WATER QUALITY ASSESSMENT AND PREDICTION MODELLING OF NAMBIYAR RIVER BASIN, TAMIL NADU, INDIA

A THESIS

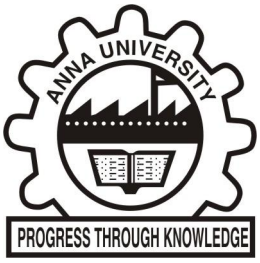
Submitted by

GAJENDRAN C

in partial fulfilment for the award of the degree

of

DOCTOR OF PHILOSOPHY



FACULTY OF CIVIL ENGINEERING

ANNA UNIVERSITY

CHENNAI 600 025

JUNE 2011

CERTIFICATE

This is to certify that all the corrections suggested by the Indian and Foreign examiners have been incorporated in the thesis of Mr.C.GAJENDRAN (Reg. No. 2006189102).

P. Tha

Dr.P.THAMARAI
(SUPERVISOR)
Associate Professor
Department of Civil Engineering
Government College of Engineering
Salem - 636 011

PROCEEDINGS OF THE Ph.D VIVA-VOCE EXAMINATION OF Mr.C.GAJENDRAN HELD AT 02.30 pm ON 04.01.2012 IN THE SEMINAR HALL, DEPARTMENT OF CIVIL ENGINEERING, GOVERNMENT COLLEGE OF ENGINEERING, SALEM - 636 011, ANNA UNIVERSITY, CHENNAI - 600 025.

The Ph.D Viva-Voce Examination of Mr.C.GAJENDRAN (Reg. No. 2006189102) on his Ph.D Thesis Entitled "WATER QUALITY ASSESSMENT AND PREDICTION MODELLING OF NAMBIYAR RIVER BASIN, TAMIL NADU, INDIA" was conducted on 04.01.2012 at 02.30 p.m. in the Department of Civil Engineering, Government College of Engineering, Salem – 636 011.
The following Members of the Oral Examination Board were present:

1. **Dr. S.Mohan** — Indian Examiner
   Director,
   National Institute of Technical Teachers Training & Research,
   Ministry of Human Resources Development, Government of India,
   Taramani, Chennai – 600 113.

2. **Dr. G.Swaminathan** — Expert Member
   Professor,
   Department of Civil Engineering,
   National Institute of Technology,
   Thiruchirappalli – 620 015.

3. **Dr.P.Thamarai** — Supervisor & Convener
   Associate Professor,
   Department of Civil Engineering,
   Government College of Engineering,
   Salem - 636 011.

The research scholar, Mr.C.Gajendran presented the salient features of his Ph.D work. This was followed by questions from the board members. The questions raised by the Foreign and Indian Examiners were also put to the scholar. The scholar answered the questions to the full satisfaction of the board members.

The corrections suggested by the Indian/Foreign examiner have been carried out and incorporated in the Thesis before the Oral Examination.

Based on the scholar's research work, his presentation and also the clarifications and answers by the scholar to the questions, the board **recommends** that **Mr.C.GAJENDRAN be awarded Ph.D degree in the Faculty of Civil Engineering.**

1. 04/01/2012 — **Dr. S.MOHAN** — Indian Examiner
2. 4/01/2012 — **Dr.G.SWAMINATHAN** — Expert Member
3. 4/1/12 — **Dr.P.THAMARAI** — Supervisor & Convener

ANNA UNIVERSITY

CHENNAI 600 025

BONAFIDE CERTIFICATE

Certified that this thesis titled "**WATER QUALITY ASSESSMENT AND PREDICTION MODELLING OF NAMBIYAR RIVER BASIN, TAMIL NADU, INDIA**" is the bonafide work of **Mr. GAJENDRAN, C.** who carried out the research under my supervision. Certified further that, to the best of my knowledge, the work reported herein does not form part of any other thesis or dissertation on the basis of which a degree or award was conferred on an earlier occasion of this or any other scholar.

SIGNATURE

Dr. P. Thamarai
SUPERVISOR
Associate Professor
Department of Civil Engineering
Government College of Engineering
Salem .

ABSTRACT

The management of river water quality is a major environmental challenge. Monitoring different sources of pollutant load contribution to the river basin is quite a difficult, laborious and expensive process which sometimes leads to analytical errors also. The main objective of the present study is to develop a model to assess and predict the water quality changes of the Nambiyar River Basin, in Tamil Nadu, India, using Neural Network and GIS techniques, and to compare the results through the statistical method. Hydro-geochemistry of groundwater in Nambiyar River basin was used to assess the quality of groundwater for determining its suitability for drinking and agricultural purposes. The cations such as Ca, Mg, Na, K and anions like HCO_3, CO_3, Cl, SO_4 and NO_3 were analysed in the laboratory.

General statistical analyses of the bio-physico and chemical parameters of the basin's surface water quality have been carried out to find the interrelationships among them, which constitute the first phase of the present study. By this study it is found that a strong correlation exists between SO_4 and COD. Maximum correlation is obtained between SO_4 and COD ($r = 0.9532$). Regression equation has been derived for surface water quality parameters corresponding to the correlation coefficient value of more than 0.8. Similarly, a systematic correlation and regression study on ground water quality, in the second phase of work, shows the linear relationship among the different water quality parameters. High correlation coefficients have been observed from TDS with Cl, Ca, SO_4 and Na; from Cl with Ca; and from SO_4 with Ca. The regression equations can be used for the rapid monitoring of the water quality of the basin.

In the third phase of the study, water quality indices of the basin have been determined. The physico-chemical parameters such as pH, DO, TDS, NO_3, BOD, COD, Total Alkalinity, Total hardness, Ca, Mg, Cl, SO_4 and F of the basin have been taken into account for deciding the quality characteristics of the basin. The samples collected from six sampling points in the basin during the years 2002 to 2006 have been used to study the surface WQI and to generate the thematic maps. Similarly 32 representative groundwater samples have been used for the study on groundwater quality index and to generate the thematic maps. For groundwater quality index study, the pre-monsoon and post-monsoon water quality parameters in the year 2009 have been taken into account. The results imply that the major part of the basin has moderate to poor surface water quality for drinking purpose and, in general, the surface water quality of the basin decreases from Northwest to Southeast. Most of the groundwater quality index for the pre- and post-monsoon seasons lies between good and excellent.

It was observed that the basin water had more amount of Hardness that resulted in large number of people suffering from health problems related to the kidney. The maximum value of hardness, viz. 3450 mg/l was observed during 1994. Since hardness in water is one of the major causes of renal calculi (kidney problems), an Intelligent Predictive Model (IPM) has been developed using ANN and GIS, for Hardness. Besides, this model can also be used to predict TDS and Cl. Due to the correlations and interactions among water quality parameters; it is interesting to investigate whether a domain-specific mechanism governing observed patterns exists to prove the predictability of the water quality variables like Hardness, TDS, and Cl. A new approach, viz. the use of ANN and GIS based analysis has been developed in this study to predict the concentrations of Hardness, TDS and Cl.

This thesis discusses the development and validation of an ANN-based model in estimating water quality of the Nambiyar River Basin. This technique is particularly suitable for problems that involve the manipulation of multiple parameters, nonlinear interpolation and significance that is not easily amenable to conventional, theoretical and mathematical approaches. The result shows, that the proposed ANN prediction model has a great potential to simulate and predict the Hardness, TDS and Cl with acceptable accuracies. Mean Square Error values are; $HARDNESS_{MSE} = 1.78177\times10^{-4}$; $TDS_{MSE} = 1.58319\times10^{-4}$ and $Cl_{MSE} = 3.23229666\times10^{-4}$. The Neural Network model has been compared with a Linear Regression Model to find out the best modelling approach for the study area, and it is concluded that the Neural Network Model is much superior to Linear Regression Model.

It is important to note that prior to this study no significant water quality study using WQI or IPM has been reported for the Nambiyar basin since 1995 to the present.

ACKNOWLEDGEMENTS

I wish to express my deep sense of gratitude to Dr. P Thamarai, Associate Professor, Department of Civil Engineering, Government College of Engineering, Salem without her guidance and supervision this work of thesis would not have been possible. Without her constant motivation and encouragement, I would not have been in a position to complete the thesis work.

I am grateful to the doctoral committee members Dr. C. Lakshumanan, and Dr. T. Subramani for their suggestions and encouragement throughout the work. I am indebted to Dr. J. Francis Lawrence for improving the quality of my thesis work. Without his involvement it would not have been possible to produce a work of this quality. I am also thankful to Dr. Nainan P. Kurian for his critical reading of the manuscript and for his valuable comments in improving the overall quality of the thesis work.

My sincere thanks to Karunya University, Coimbatore and Sardar Raja Engineering College, Alangualam for providing the necessary research facilities and for the all round help in the preparation my thesis.My heartfelt thanks to successive Chief Engineers, Superintending Engineers, Assistant Engineers of the Public Works Department, Environmental Cell, for permitting the use of the data collected by the Department and for guidance in the present work. I express my in-depth gratitude to my beloved brother Prof. C. Mahendran, My beloved sister C.Anusuya and my beloved better half Dr. Bagya Lakshmi for their patience in the last four years and for their constant prayers for me. I also thank all those who encouraged me with their valuable suggestions, co-operation and appreciation which enabled one to complete this work successfully. I wish to dedicate this work to my beloved appa Shri.Chelliah and my beloved Amma Smt.Gomathi.

C.GAJENDRAN

TABLE OF CONTENTS

CHAPTER NO	TITLE	PAGE NO
	ABSTRACT	**iii**
	LIST OF TABLES	**xiii**
	LIST OF FIGURES AND MAPS	**xvi**
	LIST OF SYMBOLS AND ABBREVIATIONS	**xix**
1.	**INTRODUCTION**	
	1.1 GENERAL	1
	1.2 NEED FOR THE STUDY	3
	1.2.1 Water Quality Problems in India	3
	1.3 OBJECTIVES OF THE PRESENT STUDY	6
	1.4 STUDY AREA	7
	1.5 DESCRIPTION OF THE CONTENTS OF THE THESIS	7
2	**LITERATURE REVIEW**	10
	2.1 GENERAL	
	2.2 HYRO-GEOCHEMISTRY	10
	2.3 STATISTICAL STUDY	13
	2.4 WATER QUALITY INDEX	17
	2.5 NEURAL NETWORK	19
	2.6 INTEGRATED APPROACHES	28

CHAPTER NO	TITLE	PAGE NO
3	**METHODOLOGY**	35
	3.1 GENERAL	35
	3.2 HYDRO-GEOCHEMISTRY	36
	3.3 STATISTICAL STUDY	36
	3.3.1 Correlation Coefficient and Linear Regression	36
	3.3.2 Pearson's r	38
	3.3.3 Water Quality Trend Study	39
	3.3.3.1 Surface Water Quality Trend	40
	3.3.3.2 Groundwater Quality Trend	40
	3.4 WATER QUALITY INDEX	40
	3.4.1 GIS Model for WQI	42
	3.5 INTELLIGENT PREDICTIVE MODEL STUDY	43
	3.5.1 Neural Network Model	43
	3.5.2 GIS Integration	45
4	**STUDY AREA**	46
	4.1 GENERAL	46
	4.2 PHYSIOGRAPHY	47
	4.3 DRAINAGE	48
	4.4 SUB-BASINS DESCRIPTION	49
	4.4.1 Karamaniyar River	49
	4.4.2 Nambiyar River	49
	4.4.3 Hanumanadhi River	50
	4.5 RELIEF	51

CHAPTER NO	TITLE	PAGE NO
	4.6 GEOLOGY	52
	4.7 HYDRO-GEOLOGY	53
	4.8 INDUSTRIES	54
	4.8.1 Power Generation	54
	4.8.2 Major Industries	55
	4.8.3 Mineral-Based Industry	55
	4.8.4 Garnet Industry	55
	4.9 NON-CONVENTIONAL ENERGY RESOURCES	56
	4.10 IMPACT OF INDUSTRIES IN THE BASIN	56
	4.11 DISEASE / HEALTH HAZARDS	57
5	**HYDRO-GEOCHEMISTRY**	58
	5.1 INTRODUCTION	58
	5.2 GROUNDWATER SAMPLING AND CHEMICAL ANALYSIS	60
	5.3 CHEMICAL QUALITY	60
	5.3.1 Units of Measurement	60
	5.3.2 Physical Parameters	67
	5.3.3 Colour	68
	5.3.4 Turbidity	68
	5.3.5 Temperature	68
	5.3.6 Taste and odour	69
	5.3.7 Density	69
	5.3.8 Bacteriological Quality	69

CHAPTER NO **TITLE** **PAGE NO**

5.4 DISSOLVED CONSTITUENTS IN GROUNDWATER 70

5.4.1 Silica 70

5.4.2 Iron 70

5.4.3 Manganese 70

5.4.4 Calcium 71

5.4.5 Magnesium 71

5.4.6 Sodium 72

5.4.7 Potassium 73

5.4.8 Carbonate and Bicarbonate 73

5.4.9 Sulphate 74

5.4.10 Chloride 74

5.5 CLASSIFICATION OF GROUNDWATER 75

5.5.1 Total Dissolved Solids 75

5.5.2 Total Hardness 76

5.5.3 Hardness 77

5.5.4 Corrosivity Ratio 78

5.5.5 Schoeller Water Type 78

5.5.6 Stuyfzand Classification 79

5.5.7 USSL Classification 79

5.5.8 Mechanism Controlling Water Chemistry 80

5.5.9 Digital Data Processing 81

CHAPTER NO **TITLE** **PAGE NO**

5.6 GROUNDWATER QUALITY ASSESSMENT 90
5.6.1 Total Dissolved Solids 90
5.6.2 Hardness 92
5.6.3 Corrosivity Ratio 94
5.6.4 Stuyfzand Classification 96
5.6.5 USSL Classification 96
5.6.6 GIBB's Plot 98
5.6.7 Piper's Tri-linear diagram 99

6 STATISTICAL STUDIES 100
6.1 SURFACE WATER QUALITY TREND STUDY 100
6.1.1 GENERAL 100
6.2 WATER QUALITY TREND STUDY FOR GROUNDWATER 113
6.3 STATISTICAL STUDY ON GROUNDWATER QUALITY 128
6.4 CORRELATION ANALYSIS BETWEEN GROUNDWATER QUALITY AND SURFACE WATER QUALITY 136

7 WATER QUALITY INDICES 138
7.1 GENERAL 138
7.2 WATER QUALITY INDEX BY SURFACE WATER SOURCES 138

CHAPTER NO	TITLE	PAGE NO
	7.3 WATER QUALITY INDEX BY GROUND WATER SOURCES	146
8	**INTELLIGENT PREDICTIVE MODEL**	153
	8.1 GENERAL	153
	8.2 DATA COLLECTION AND ANALYSIS	154
	8.3 NEURAL NETWORK MODEL	157
	8.4 GIS INTEGRATION	157
	8.5 CORRELATION OF PHYSICOCHEMICAL PARAMETERS	162
	8.6 REGRESSION	165
	8.7 NEURAL NETWORK MODEL	166
	8.7.1 Data Partition	167
	8.7.2 Total Dissolved Solids model	167
	8.7.3 Chloride Model	169
	8.7.4 Hardness Model	169
	8.7.5 Model Performance Evaluation	169
9	**CONCLUSION**	171
	9.1 GENERAL	171
	9.2 SUMMARY AND CONCLUSIONS	171
	9.3 SCOPE FOR FUTURE WORKS	177
	APPENDIX	178
	REFERENCES	185
	LIST OF PUBLICATIONS	205
	CURRICULAR VITIATE	206

LIST OF TABLES

TABLE NO	TITLE	PAGE NO
5.1	Sample Points Location ID Details	62
5.2	Groundwater Quality Analysis Result in Pre - Monsoon Period	63
5.3	Groundwater Quality Analysis Result in Post – Monsoon Period	65
5.4	Groundwater Classification on the Basis of TDS	76
5.5	Classification of Water Based on Hardness	77
5.6	Stuyfzand Classifications	79
5.7	Sources of Basic Criteria Used in HYCH	81
5.8	Basic Criteria Used in Handa's Classification	82
5.9	Classification of Hydrochemical Facies	83
5.10	Stuyfzand's Water Types Based on Saturation Index	83
5.11	HYCH Output Results of the Study area Pre Monsoon	85
5.12	HYCH Output Results of the Study area Post Monsoon	87
6.1	Descriptive Statistics for Surface Water Quality Parameters	103
6.2	Correlation Coefficients Among Various Surface Water Quality Parameters	105
6.3	Regression Summary Output - pH and DO	107
6.4	Regression Summary Output - N (NO_3+NO_2) and DO	108
6.5	Regression Summary Output - TDS and SO_4	109
6.6	Regression Summary Output - Ca^{++} and SO_4	110

TABLE NO **TITLE** **PAGE NO**

6.7	Regression Summary Output - TDS and COD	111
6.8	Regression Summary Output - SO_4 and COD	112
6.9	Regression Equations for Surface Water Quality Parameters	113
6.10	Groundwater Sample Points Locations ID Details	116
6.11	Statistical Parameters of Groundwater Qualities	118
6.12	Correlation Coefficients among Various Groundwater Quality Parameters	120
6.13	Regression Equations for Groundwater Quality Parameters	121
6.14	Regression Summary Output - TDS and Cl	122
6.15	Regression Summary Output - TDS and Ca	123
6.16	Regression Summary Output - Cl and Ca	124
6.17	Regression Summary Output - TDS and SO_4	125
6.18	Regression Summary Output - TDS and Na	126
6.19	Regression Summary Output - SO_4 and Ca	127
6.20	Groundwater Sample Points Location ID Details	130
6.21	Summary of Groundwater Quality Parameters	132
6.22	Correlation Matrix of Groundwater Physiochemical Parameters	134
6.23	Regression Equations for Groundwater Quality Parameters	135
6.24	Correlation Coefficient between Various Groundwater and Surface Water Quality Parameter	137
7.1	WQI Categories	140
7.2	Study area Locations ID Details	148
7.3	Relative Weight of Chemical Parameters	149

TABLE NO	TITLE	PAGE NO
7.4	Water Quality Classifications Based on WQI Value	151
8.1	Intelligent Predictive Model Sample Points Location ID Details	156
8.2	Summary of Water Quality Parameters	163
8.3	Correlation Matrix of Physio-chemical Parameters	164

LIST OF FIGURES AND MAPS

FIGURE NO	TITLE	PAGE NO
1.1	Study area Location Map	8
3.1	Methodology Flow Chart for Hydrochemical Study	37
3.2	Methodology flow Chart for WQI Study	44
5.1	Water Quality Classification Sample Point Location Map	61
5.2	Computer Output of HYCH Program	89
5.3	Spatial Variation of Total Dissolved Solids during January 2009	91
5.4	Spatial Variation of Total Dissolved Solids during July 2009	91
5.5	Spatial Variation of Total Hardness during January 2009	93
5.6	Spatial Variation of Total Hardness during July 2009	93
5.7	Spatial Variation of Corrosivity Ratio during January 2009	95
5.8	Spatial Variation of Corrosivity Ratio during July 2009	95
5.9	USSL Classification of Groundwater	97
5.10	GIBB'S Plot of Groundwater	98
5.11	Distribution of the water samples on Piper's diagram	99
6.1	Sample Point Location Map For Surface Water Quality Trend Study	102
6.2	Regression between pH and DO	107
6.3	Regression between as N (NO_3+NO_2) and DO	108

FIGURE NO **TITLE** **PAGE NO**

6.4	Regression between TDS and SO_4	109
6.5	Regression between Ca^{++} and SO_4	110
6.6	Regression between TDS and COD	111
6.7	Regression between SO_4 and COD	112
6.8	Sample Points Location Map For Groundwater Quality Trend Study	115
6.9	Regression between TDS and Cl	122
6.10	Regression between TDS and Ca	123
6.11	Regression between Cl and Ca	124
6.12	Regression between TDS and SO_4	125
6.13	Regression between TDS and Na	126
6.14	Regression between SO_4 and Ca	127
6.15	Sample Points Location Map for Groundwater Quality Statistical Study	129
7.1	Sample Points Location Map of Surface Water Quality Index Study	141
7.2	Surface Water Quality Index for the Year 2002	143
7.3	Surface Water Quality Index for the Year 2003	144
7.4	Surface Water Quality Index for the Year 2004	144
7.5	Surface Water Quality Index for the Year 2005	145
7.6	Surface Water Quality Index for the Year 2006	145
7.7	Sample Points Location Map for Water Quality Index Study on Groundwater Quality	147
7.8	Water Quality Index Map – Pre-Monsoon Period	151
7.9	Water Quality Index Map – Post-Monsoon Period	152
8.1	Intelligent Predictive Model Sample Points Location Map	155
8.2	Neural Network Flow Diagram	157
8.3	TDS Model Output Map of the Study Area	159

FIGURE NO **TITLE** **PAGE NO**

8.4	Chloride Model Output Map of the Study Area	160
8.5	Hardness Model Output Map of the Study Area	161
8.6	Total Dissolved Solids Regression Model Output	165
8.7	Chlorine Regression Model Output	166
8.8	Hardness Regression Model Output	166
8.9	ANN Prediction Model for TDS	168
8.10	ANN Prediction Model for Cl	168
8.11	ANN Prediction Model for Hardness	168

LIST OF SYMBOLS AND ABBREVIATIONS

AI	-	Artificial Intelligence
AN	-	Ammoniacal-Nitrate
ANN	-	Artificial Neural Network
APHA	-	American Public Health Association
BIS	-	Bureau of Indian Standards
BNN	-	Bayesian Neural Network
BOD	-	Biochemical Oxygen Demand
BPNN	-	Back-propagation Neural Network
C	-	Celsius
CCANN	-	Cascade Correlation Artificial Neural Network
cm	-	Centimeter
COD	-	Chemical Oxygen Demand
cu.m	-	Cubic meter
DO	-	Dissolved Oxygen
EC	-	Electrical Conductivity
FFNN	-	Feed Forward Neural Network
GIS	-	Geographical Information Systems
GSI	-	Geological Survey of India
ICMR	-	Indian Council of Medical Research
IDW	-	Inverse Distance Weighted
IPM	-	Intelligent Predictive Model
kg	-	Kilogram
km	-	Kilometer
mbgl	-	Metres below ground level
m	-	Metre
MCM	-	Million Cubic Metres
mg	-	Milligram

mgd	-	Million gallons per day
ml	-	Millilitre
MLP	-	Multi Layer Perceptrons
MLR	-	Multi Linear Regression
mm	-	Millimetre
MSL	-	Mean Sea Level
MVRA	-	Multivariate Regression Analysis
N	-	Normality
ppm	-	Parts per million
RMLP	-	Recurrent Multi-Layer perceptrons
RMSE	-	Root Mean Square Error
S	-	Specific yield
SAR	-	Sodium Adsorption Ratio
Sec	-	Second
Sq.km	-	Square kilometre
SS	-	Suspended Solids
STTF	-	Short Term Temperature Forecasting
t	-	Time
TDS	-	Total Dissolved Solids
TLFN	-	Time-Lagged Feed-forward Networks
TNPWD	-	Tamil Nadu Public Works Department
USSL	-	United States Salinity Laboratory
WHO	-	World Health Organisation
WQI	-	Water Quality Index
’	-	Minutes
”	-	Seconds
µS	-	Micro Siemens
µS/cm	-	Microsecond per centimetre
^{0}	-	Degree

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Water is the most important natural resource not only of a state or a country, but of the entire humanity. The prosperity of a nation depends primarily upon the judicious exploitation of this resource. Thus, it can be stated that the primary wealth of a nation is water, which flows in rivers and streams. This itself establishes the importance of rivers, and no other explanation is required to stress their importance. River basin, as a domain for planning and management has been accepted the world over, as water does not recognize political boundaries. Among the most distinctive features of India are its rivers which hold high religious importance among its people. Covering the vast geographical area of 329 million hectares, Indian rivers have been an important reason for the rural prosperity of India. Being of wider importance in cultural, economical, geographical as well as religious development, its numerous rivers are of great value to India. The rivers in India are considered as Gods and Goddesses, and are even worshiped by the Hindus. They provide tourists a wonderful insight into the historical, cultural and traditional aspects of India. Among various types of inland fresh water bodies, the riverine system is a unique type of ecosystem. The size of the drainage basin, the amount of water moving through the system, the proportion of natural versus settled areas, and man's direct impacts are all key factors determining the quality and characteristics of each watershed.

India with declining freshwater resources has an acute shortage of potable water of acceptable quality. The socio-economic growth of a region is severely constrained by non-availability of safe drinking water; keeping this in view, Government of India had constituted a Water Technology Mission for drinking water in 1987. The task of planning and management of water resources can be very effectively carried out on a basin wise structure for all infra, intra and interstate as well as international rivers using scientific techniques.

A world water development report by United Nations had categorized India as one among the worst countries with poor quality of water, as well as its ability and commitment to improve the situation. Belgium is considered the worst basically because of the low quantity and quality of its groundwater combined with heavy industrial pollution and poor treatment of wastewater. It is followed by Morocco, India, Jordan, Sudan, Niger, Burkinafso, Burundl, Central African Republic and Rwanda. Attributing this to “inertia at leadership level” the report entitled “Water for people, Water for life” observes that “the global water crisis will reach unprecedented levels in future with growing per capita scarcity of water in many parts of the developing world.” The report compiled on the eve of the Third World Water Forum held at Kyoto, Japan, March 16, 2003, by 23 UN partners constituting the World Water Assessment programme (WWAP) under UNESCO (The Hindu, May 21, 2003). The surface and groundwater resources are steadily declining because of increase in population, industrial growth, pollution by various human, agricultural and industrial wastes and unexpected climate change.

1.2 NEED FOR THE STUDY

1.2.1 Water quality problems in India

The shortage of water in the country has started affecting the lives of people as well as the Environment around them. Some of the major issues that need urgent attention are:

- As a result of excessive extraction of ground water to meet agriculture, industrial and domestic demands, drinking water is not available during the critical summer months in many parts of the country.
- About 10 per cent of the rural and urban populations do not have access to regular safe drinking water and many more are threatened. Most of them depend on unsafe water sources to meet their daily needs. Moreover, water shortages in cities and villages have led to large volumes of water being collected and transported over great distances by tankers and pipelines.
- Chemical contaminants namely fluoride, arsenic and selenium pose a very serious health hazard in the country. It is estimated that about 70 million people in 20 States are at risk due to excess fluoride and around 10 million people are at risk due to excess arsenic in ground water. Apart from this, increase in the concentration of Chloride, TDS, Nitrate, Iron in groundwater is of great concern for a sustainable drinking water programme. All these need to be tackled holistically. With over extraction of groundwater the concentration of

dissolved constituents/ionic concentrations is increasing regularly.

- Ingress of seawater into coastal aquifers as a result of over-extraction of ground water has made water supplies more saline, unsuitable for drinking and irrigation.

- Pollution of surface and groundwater from agro-chemicals (Fertilizers and Pesticides) and from industry poses a major environmental health hazard, with potentially significant costs to the country. The World Bank has estimated that the total cost of environmental, damage in India amounts to US$9.7 billion annually, or 4.5 per cent of the gross domestic product. Of this, 59 per cent results from the health impacts of water pollution (World Bank 1995).

In recent times, the demand for water has increased many folds due to increased domestic and industrial needs. The development of water resources in a river basin is not a goal by itself, but a means to reach the socio-economic objectives of production, income, employment and quality of life. Therefore, water resources development should be considered in the wider context of regional planning. Such a plan needs a systematic study in the basin to know the spatial distribution of water quality so that any sustainable approach could be implemented in the river basin. Thus, in order to meet society's need for water, preventive measures must be taken to ensure the sustainability of the water resources. Keeping the above criteria in mind, an attempt has been made in water quality assessment and prediction modelling of Nambiyar river basin, in the State of Tamil Nadu in India.

A detailed study on Hydro-geochemistry of the basin has been carried out, for a better understanding of the basin's surface and groundwater qualities.

A general statistical study and analysis on the bio-physico and chemical parameters of the basin's surface water quality have been carried out to find the interrelationship among them and also to know the water quality trends in the basin.

The regression equation has been derived for the surface water quality parameters corresponding to the correlation coefficients whose value is more than 0.8. These equations can be used for the rapid monitoring of the surface water quality of the basin.

Similarly, a systematic correlation and regression study on ground water qualities in the study area showed linear relationship among the different groundwater quality parameters. This provides a lucid and rapid method of monitoring ground water qualities of the basin.

Water quality index of the basin has been determined. Water quality index is a means to summarize large amount of water quality data into simple terms (e.g., 'Good' or 'Bad', 'Clean' or 'Contaminated') for reporting to authorities, management and the public in a consistent manner.

ANN based predictive model has been developed to predict Hardness, TDS and Cl. A study is also carried out to identify the best location of the basin for different sustainable developmental activities in the basin.

It is important to note that prior to this work no significant study on water quality using statistical approach, WQI, and IPM has been reported in the Nambiyar basin.

1.3 OBJECTIVES OF THE PRESENT STUDY

1. To study the Hydro-geochemistry of the basin.
2. To identify optimized locations for different usages in the present study area.
3. To study the water quality trends in the basin.
4. To identify the interrelationship among the bio-physico and chemical parameters of the basin water quality using a statistical approach for both surface and ground water.
5. To find the Water Quality Index (WQI) of the basin.

The purposes of the investigation of WQI are:

   a. To provide an overview of the quality of the basin,
   b. To determine the spatial distribution so that the trend of the water quality can be assessed for future development plans, and
   c. To map surface and groundwater quality changes in the study area using GIS and Geo-statistical techniques.

6. To identify potential equivalences between Artificial Neural Networks (ANN) and statistical regression model to find the best modelling approach for the study area.
7. To give recommendations based on the study of the Nambiyar River Basin to water quality management authorities on how the results can be integrated for sustainable catchment management strategies of the basin.

1.4 STUDY AREA

Nambiyar River basin is situated in the southernmost part of South India and is located between altitudes of 8 °08’ and 8° 33’ N and longitudes of 77° 28’ and 78° 15’ E. The total area of the basin is 2084 sq.km. The Nambiyar basin spreads over Tirunelveli and Thoothukudi districts of the State of Tamil Nadu. The study area is bounded by Tamiraparani basin in the north, Pacchayar and Valliyoor basins in the west, Bay of Bengal in the east and Indian Ocean in the south. Figure 1.1 gives the location map of the study area. The basin is named after the major river in the basin, viz. Nambiyar; other minor rivers flowing in this basin are Karumeniar and Hanumanadhi. The river Karamaniyar flows in the basin at the eastern part of the basin from northwest to southeast, passing through Sattankulam and confluences with the Gulf of Mannar at Kulasekaranpattinam. Nambiyar River originates at an elevation of 1479 m above MSL in Nalikkal Mottai in Kallakadu reserved forest. It traverses through Pudukulam, Pettaikulam and confluences with the Gulf of Mannar at Thiruvambalampula. The river Hanumanadhi originates at an elevation of 1100 m above MSL in Mahendragiri reserved forest. It traverses through Panakkudi, Vadakankulam and finally confluences with the Gulf of Mannar at south of Erukkamkulam.

1.5 DESCRIPTION OF THE CONTENTS OF THE THESIS

This thesis comprises seven chapters.

1. Chapter 1 brings out the practical and scientific importance of the problem and the need of its solution for use in real life applications. The background of the study and objectives are also described in this chapter.

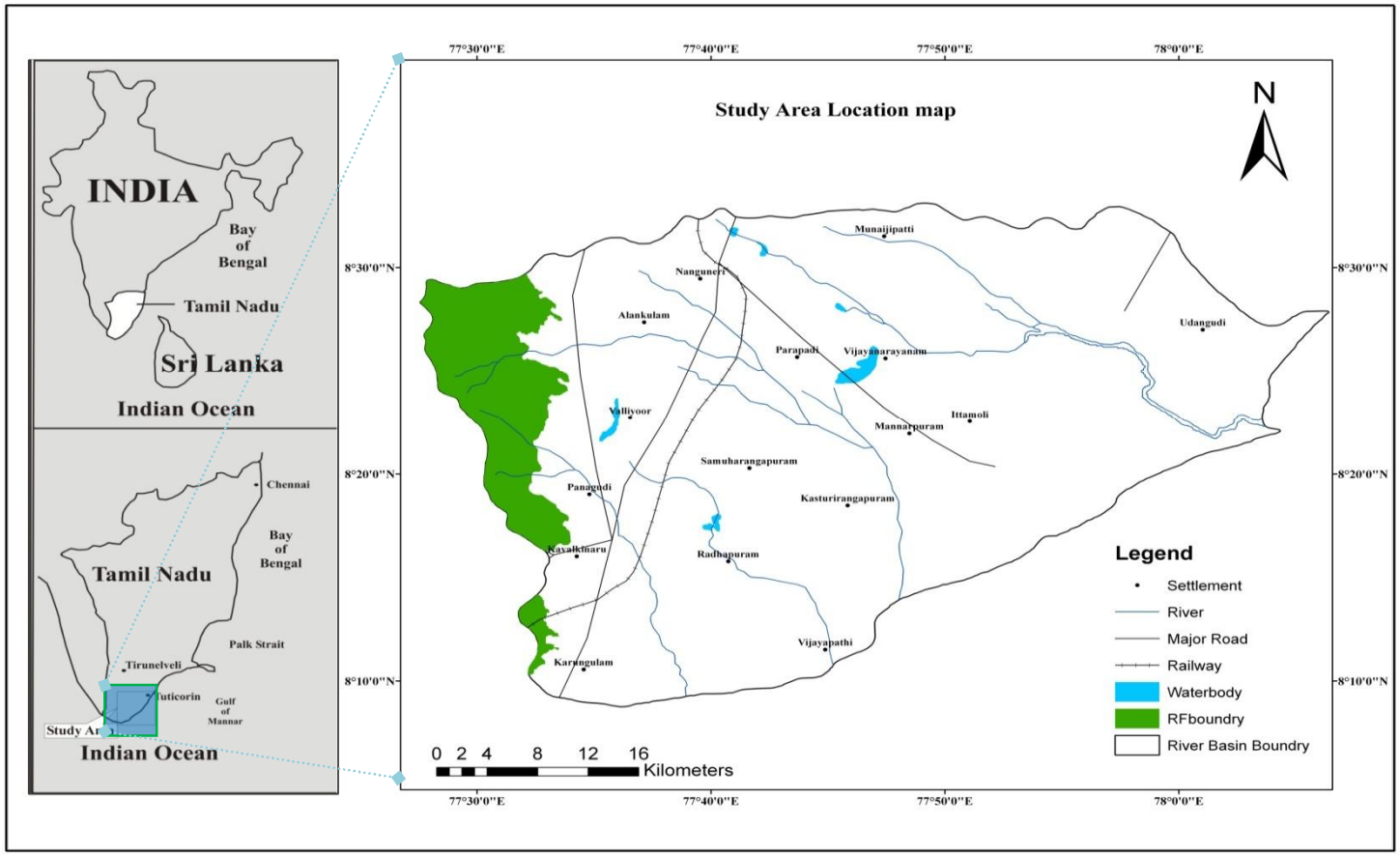


Figure 1.1 Study area Location Map

2. Chapter 2 gives the detailed review of the published literature with reference to statistical study on river basins, finding Water Quality Index for river basins, Neural Network application and water quality predictive model studies.

3. Chapter 3 deals the methodology adopted for the research. Analysis like correlation, regression, mean, and other statistical parameters, WQI, Neural Network approach and its features to predict the water quality of the study area is explained in detail.

4. Chapter 4 describes the salient features of the study area, viz. Nambiyar River Basin, in Tamil Nadu, India.

5. Chapter 5 deals with the detailed Hydro-geochemistry study of the study area.

6. Chapter 6 provides the statistical study on surface and groundwater qualities, water quality trends of the study area, and interrelationships among the water qualities.

7. Chapter 7 deals with Water Quality Index of the study area for surface and groundwater sources.

8. Chapter 8 provides a detailed description on Intelligent Prediction Modelling, and its application in the study area.

9. Chapter 9 comprises summary of this study and conclusions. The scope of further research is also explained in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

Water resources have been the most exploited natural system, since man strode the earth. As a result of increasing industrialization, urbanization, civilization and other developmental activities, our natural water system is being polluted by different sources. The pollutants coming as a waste to the water bodies are likely to create nuisance by way of physical appearance, odour, taste, quality and render the water harmful for utility. So there is an urgent need for the rapid monitoring of the quality of water resources. Rapid increase of industrialization, urbanization, and population increase in the last few decades have caused a dramatic increase in the demand for river water, as well as significant deteriorations in water quality throughout the world (Chun et al 2001).

2.2 HYRO-GEOCHEMISTRY

Lawrence et al (1976) demonstrated the mixing of different groundwater types in the limestone aquifer of England by detailed hydrochemistry studies. The distribution of ions in groundwater showed mixing of ancient connate water with the younger recharge water along an interface zone.

Agro-chemicals are the main sources of nitrogen, and other organic and inorganic contaminants in the groundwater regime. Several authors have reported the presence of agro-chemicals in soils (Muir and Baker, 1978).

Sage and Llyor (1978) demonstrated the application of hydrochemistry to understand the sandstone aquifer of England.

Freeze and Cherry (1979) studied water chemistry in combination with groundwater hydraulics.

Stumn and Morgan (1981) introduced many innovative ideas on water chemistry and its relation to its geological environment.

Studies carried out by Edmunds and Walton (1983), Scanlon (1989) and Groves (1992) revealed the importance of hydrochemical studies in recharge and flow mechanisms in the limestone aquifers.

Ophori and Toth (1989) studied the patterns of groundwater chemistry in the unconfined aquifer of Ross Creek basin of Canada using all the major ion constituents and determined the flow directions. They further showed good correlation between groundwater flow and geochemical patterns.

Cerling et al (1989) used cation exchange of Ca^{2+} ions with Na^{+} ions to explain the aqueous chemistry of waters draining shale bedrock regions. Clay mineral cation exchange properties also were studied in an effort to understand soil development in a montage area in New Zealand (Harrison et al 1990).

Hendry and Schwartz (1990) studied the chemical evolution of groundwater in the Milk river aquifer of Canada and observed well-defined

ion composition trends in the groundwater. They determined a few geochemical processes, which altered the recharge water ionic concentrations.

Elango (1992) had studied the hydro-geochemical nature of the multi-layered aquifer of North Chennai, and had brought out the relation of groundwater recharge to flow mechanisms.

Geochemical studies of waters have been utilised to help define the hydrology of an area (Konhauser et al 1994). For example, the Amazon River waters were examined geochemically and the controlling factor on the water chemistry were determined to be substrate lithlogy and soil geochemistry of the erosion regime.

The contribution of groundwater to the chemical character of stream and river waters was studied using water chemistry (Ferguson et al 1994, Williams et al 1990, Dethier 1988).

Hudson and Golding (1997) reported that bicarbonate, silica, calcium and sodium are derived from the weathering of plagioclase, while magnesium and potassium are derived from the relatively less weatherable feldspars.

Scheytt (1997) investigated seasonal and temporal variation patterns of groundwater chemistry and depthwise chemical composition of groundwater at various locations. Near the water table, groundwater was mainly influenced by recharge of rainfall.

Elango et al (1999) carried out hydro-geochemical studies in an intensively cultivated region of Tamil Nadu, India, and stressed the importance of regular monitoring of water quality parameters.

Elango et al (2003) carried out extensive work on the hydro-geochemical nature of groundwater in an intensively irrigated region of Kancheepuram District of Tamil Nadu, South India. They also emphasised the need for regular monitoring of groundwater quality.

Mohan et al (2000) attempted to assess the suitability and causes for deterioration of groundwater quality in Nainin industrial area of Allahabad District of Uttar Pradesh, by evaluating the hydro-geochemical nature of the groundwater.

Subramani et al (2005) studies the variation of groundwater quality and its suitability for drinking and agricultural use in Chithar River basin, Tamil Nadu, India.

Reviews made in the journals and publications reveal that Hydro-geochemistry study on river basin will be helpful for monitoring the water quality in the basin.

2.3 STATISTICAL STUDIES

Thengaonkar and Kulkarni (1971) studied the relationship between the alkalinity and fluoride, chloride and sulphate by analysing 45 random samples of groundwater. They found positive correlation coefficient with values of about 0.86 between the above mentioned parameters.

Tiwari et al (1986) studied the correlation among physico-chemical factors of ground waters of 50 wells located in and around Meerut city, Uttar Pradesh, India. Tiwari et al (1986 a) have obtained a linear relationship between COD and BOD for river Ganga at Kanpur, India.

Correlation coefficients among the water quality parameters of different watercourses of the country were reported by many authors. Tiwari and Manzoor (1988) used the regression and cluster analysis of water quality parameters of groundwater in Nuzvid town of Andhra Predesh.

Tiwari and Manzoor (1989) did the regression analysis of water quality parameters of groundwater at Nuzurdi town, Krishna district of Andra Pradesh, India.

Statistical analysis of water quality parameters in Roorkee was reported by Garg et al (1990).

Statistical methods such as regression analysis, multivariate analysis, Bayesian theory, pattern recognition and least square approximation models have been applied to a wide range of disciplines (Buntine and Weigend 1991).

The correlationships among the numerous parameters facilitate the task of rapid monitoring of the status of pollution in that area (Kanan and Rajashekharan 1991, Shrivastava 1991) and may prove to be a boon in India and other developing countries where the laboratory facilities and trained manpower are inadequate.

Correlation between different pairs of water quality parameters for different groundwater samples, collected at different places of a region, provides an idea about the hydrochemistry of the water sources in the region (Sanjay Kumar 1993).

Statistical investigation offers more attractive studies in environmental science, though it deviates much from real situations (Nemade and Shrivastava 1996, 1997a, 1997b).

Many workers (Aravinda 1991, Singanan and Somasekhara 1995, Biswal et al 2001, Mishra et al 2003, Mor et al 2002, Keshvan and Parameswari 2005, Prajapati and Mathur 2005, Patowary and Bhattacharya 2005) have unertaken statiscitcal analysis and assessed the ground water quality in different parts of the country.

Singh (1996) made a systematic study of correlations among 14 water quality parameters by considering 35 locations in Jhunjhunu district of Rajasthan, India, and obtained neither perfect positive nor perfect negative correlation between any two parameters. Correlation coefficient obtained is greater than or equal to 0.6 between nine pairs of parameters, with 0.858 between calcium and total hardness, high correlation between carbonates and bicarbonates, and low correlation between sodium and magnesium, magnesium and potassium, and sodium and potassium.

Singh and Choudhary (1996a) attempted to obtain some correlation among physico-chemical water quality parameters of Nagpur District, India and concluded that large positive correlation between chloride and total dissolved solids, and electrical conductivity at 25^0C and total dissolved solids, can be obtained.

Jeyaraj et al (2001) carried out a correlation study on Bharathi Nagar of Trcihirapalli city, and found the significant positive correlation existing between EC, TDS, Hardness, Alkalinity and Calcium concentration.

Indirect methods to study source contributions of pollutant loads are essential to control water quality degradation in rivers. Especially in the rivers draining large basins, the application of direct methods/collection of data will be a major constraint (Sekhar 2001).

Achuthan Nair et al (2005) concluded that the correlation study and correlation coefficient values can help in selecting treatments and to minimize contaminates in ground water.

Regression models are useful especially when only limited data. i.e., receiving water quality and low data are available in the developing countries like India. Chandrasekhar and Satyaprasad (2005) successfully made a Regression model to study Krishna river basin.

Kalyanaraman and Geetha (2005) identified that the water quality of ground water can be predicted with sufficient accuracy just by measurement of EC alone. This provides easy a means for easier and faster monitoring of water quality in a location.

Mahajan et al (2005) identified that all the parameters are more or less correlated with others, in the correlation and regression study of the physio-chemical parameters of ground water.

Sunitha et al (2005) identified that the EC finds higherlevel correlation significance with many of the water quality parameters, like Total Dissolved Solids, Chlorides, Total Alkalinity, Sulphates, Carbonates, Total hardness, and Magnesium.

Dash et al (2006) found a systematic linear relationship between different pairs of water quality parameters in Angul-Talcher industrial zone, Orissa, in their study; they took July 2001 to June 2003 physico-chemical water quality data of 7 tube well samples.

Ibrahim Bathusha and Saseetharan (2006) concluded in their study on physio-chemical characteristic of 36 samples in the selected location of Coimbatore city, that the electrical conductivity and total dissolved solids are

having high correlation with most of the other parameters. They also reveal that, by making measurement of the EC, the concentration of TDS, Hardness and Chlorides can be estimated.

Wagh and Shrivastava (2007) studied the relation between COD and BOD in sewage and ground water samples in Nasik city in India, and they proposed a relationship, BOD = b (COD) + a, to predict the value of BOD as function of COD.

Reviews made in the journals and publications reveal that statistical study on water quality will be helpful as rapid method of water quality monitoring and prediction.

The quality of water is described by its physical, chemical and microbial characteristics. But, if some correlations are possible among these parameters, then significant ones would be useful to indicate the quality of water.

2.4 WATER QUALITY INDEX

Landwehr (1979) suggested the use of Pearson-type 3-distribution function to represent the sub-indices of all the quality variables.

Horton (1965) proposed the first water quality index. A number of indices have been developed to summarize water quality data in an easily expressible and easily understood format (Couillard and Lefebvre 1985).

WQI is desired to provide assessment of water quality trends for management purposes even though it is not meant especially as an absolute measure of the degree of pollution or the actual water quality (Anonymous 1997).

According to Nives (1999), WQI is a mathematical instrument used to transform large quantities of water quality data into a single number which represents the water quality level while eliminating the subjective assessments of water quality and biases of individual water quality experts.

Water quality of different sources has been communicated on the basis of calculated water quality indices (Pradhan et al 2001).

WQI was first seriously proposed and demonstrated beginning in the 1970s but were not widely utilized or accepted by agencies that monitor water quality (Cude 2003).

WQI, in common with many other index systems, relates to a group of water quality parameters to a common scale and combines them into a single number in accordance with a chosen method or model of computations (Mohsen 2007).

Some of the indices have since been incorporated into water quality indices and used by agencies such as the National Sanitation Foundation (NSF) (Ahamed et al 2004).

WQI has been regarded as one of the most effective way to assess the quality of water (Tiwari and Mishra 1985 and Sinha et al 2004).

Sinha and Ritesh (2006) find the WQI for drinking water at Hasanpur, J.P Nagar for 10 different sites, and concluded that the water is severely contaminated at almost all the sites of sampling. They proved WQI is an important tool for the assessment of water quality.

Rita et al (2011) made a study on seasonal variation and WQI of Sabarmati River at Ahmedabad, Gujarat, India. The results of their study

revealed that the quality of Sabarmati River was adversely affected by discharge of domestic, agricultural and industrial effluents as a result of extended urbanization.

Review made in the journals and publications reveal that WQI study on river basin will be helpful for monitoring and prediction of the basin water quality.

2.5 NEURAL NETWORK

Over the past decade, Artificial Neural Network (ANN) research has found its way into the areas of hydrology, ecology, medical and other biological fields. The American Society of Civil Engineers wrote a report to investigate the usage of ANNs in hydrologic applications, and found it being used for such purposes as rainfall-runoff modelling, stream flow forecasting, groundwater modelling, precipitation prediction, and water quality issues.

Neural network models are attractive to decision makers because of their established methodology, long history of application, availability of software and deep-rooted acceptance among practitioners and academicians alike. Many researchers showed that the ANN model gives a better performance compared to the other model in forecasting water quality. Applications of ANN in the areas of water engineering, ecological sciences, and environmental sciences have been reported since the beginning of the 1990s.

The applications of neural networks have increased rapidly in the field of water quality management (Wen and Lee 1998) economic analysis, water resources planning and hydrologic time series, as described in Chakraborty et al (1992), Lachtermacher and Fuller (1994) and Schizas et al (1994).

In recent years, ANNs have been used intensively for prediction and forecasting in a number of water-related areas, including water resource study (Liong et al 1999, Muttil and Chau 2006, El-Shafie et al 2008), oceanography (Makarynskyy 2004), and environmental science and river water quality (Grubert 2003) and land slide mapping (Vahidnia et al 2010).

Reckhow (1999) studied Bayesian probability network models for guiding decision making regarding water quality in the Neuse River in North Carolina.

Bowers (2000) developed a model to predict suspended solids considering local precipitation, stream flow rates and turbidity as input.

Holger and Dandy (2000) presented a review of modelling issues and applications on Neural Networks for the prediction and forecasting of water resource variables. In their paper, the steps that should be followed in the development of such models are outlined. These include the choice of performance criteria, the division and pre-processing of the available data, the determination of appropriate model inputs and network architecture, optimization of the connection weights (training) and model validation. The vast majority of the networks are trained using the back-propagation algorithm.

The use of data-driven techniques for modelling the quality of both fresh water (Chen and Mynett 2003) and sea water (Lee et al 2000, 2003) has met with success in the past decade.

Ayman (2003) has conducted an investigation on water quality sensing using Multi-layer Perceptron ANNs. The classification of water quality data is a typical pattern recognition problem that poses many difficulties. Traditional methods for classifying high volumes of such data

into large numbers of classes based on statistical parametric methods often do not give sufficient descriptive accuracy for discriminating the numbers of classes required. The use of multilayer perceptron neural networks as a new method for solving this problem for realistic operational purposes was established. The multilayer perceptron offers a good classification method and competes well with the traditional techniques used in statistical parametric methods. Indeed by using reasonably large network architectures, the method seems to work quite well with large numbers of classes where problems are normally encountered with the traditional parametric methods. The neural networks have much potential in water quality sensing and they can also be integrated into operational applications in the future.

Zaheer and Bai (2003) have made study on an application of ANN for water quality management. ANN based decision-making approach for water quality management to control environmental pollution is presented in their work. Previous research on water quality management problems has shown that traditional optimization techniques and an expert-system approach do not provide an educated solution comparing with decision making approach, which is related to the interpretation of data based on certain set of rules. Under such conditions, the ANN learns the rule governing the decision-making through a series of experiments.

Satish et al (2004) have done a study on finding the effect of temperature on short term load forecasting using an integrated ANN. Four modules consisting of the Basic ANN, Peak and Valley ANN, Averager, and Forecaster and Adaptive Combiner form the integrated method for load forecasting. The Basic ANN uses the historical data of load and temperature to predict the next 24 h load, while the Peak and Valley ANN uses the past peak and valley data of load and temperatures, respectively. The Averager captures the average variation of the load from the previous load behaviour,

while the adaptive combiner uses the weighted combination of outputs from the Basic ANN and the Forecaster, to forecast the final load. The regression-based and time-series methods are conceptually incorporated into the ANN to obtain an integrated load forecasting approach in their study.

Muhammad et al (2004) have made a study on forecasting ground water contamination using ANN. In their study, a Neural Network Model for forecasting the concentration of different hazardous metals in groundwater has been developed. ANN model was used for future prediction of the quantities of different effluents. The model was applied to real data from groundwater in Faisalabad, the largest industrial city of Pakistan. The city has more than 8000 big and small industrial units. Satiana road sludge carrier in Faisalabad city, receiving effluents of a large number of textile mills, laundries and other factories was selected for the future prediction of quantities of heavy metals (Fe, Cu and Pb) in groundwater due to seepage from the carrier. The data for both the lined and unlined channel was obtained from Pakistan Council of Research in Water Resources. The results obtained from the model were compared with actual values as well as the World Health Organization Standards.

Mafia et al (2005) have studied the use of a Neural Network technique for the prediction of water quality parameters. Their paper is concerned with the use of Neural Network models for the prediction of water quality parameters in rivers. ANNs were developed for the prediction of the monthly values of three water quality parameters of the Strymon River at a station located in Sidirokastro Bridge near the Greek-Bulgarian borders by using the monthly values of the other existing water quality parameters as input variables. The monthly data of thirteen parameters and the discharge, at the Sidirokastro station, for the time period 1980-1990 were selected for this analysis. The results demonstrated the ability of the appropriate ANN models

for the prediction of water quality parameters. This provides a very useful tool for filling the missing values that is a very serious problem in most of the Greek monitoring stations.

Chau (2006) has reviewed the development and current progress of the integration of artificial intelligence (AI) into water quality modelling.

Diamantopoulou et al (2007) made a study to estimate the missing monthly values of water quality parameters in rivers using Cascade Correlation Artificial Neural Network (CCANN).Three-layer CCANN models were developed to predict the monthly values of some water quality parameters in rivers by using monthly values of other existing water quality parameters as input variables. The monthly data of some water quality parameters and discharge, for the time period 1980–1994, of Axios River, at a station near the Greek-FYROM borders and for the time period 1980–1990, of Strymon River, at a station near the Greek-Bulgarian borders, were selected for their study. The training of CCANN models was achieved by the cascade correlation algorithm which is a feed-forward and supervised algorithm. Kalman's learning rule was used to modify the ANN weights. The choice of the input variables introduced to the input layer was based on the stepwise approach. The number of nodes in the hidden layer was determined based on the maximum value of the correlation coefficient. The final network architecture and geometry were tested to avoid over-fitting. The selected CCANN models gave very good results for both rivers and seem promising to be applicable for the estimation of missing monthly values of water quality parameters in rivers.

Muluye and Coulibaly (2007) have done a study on seasonal reservoir inflow forecasting with low frequency climatic indices: a comparison of data-driven methods. This study investigates the potential of

using data-driven methods, namely Bayesian Neural Networks (BNN), Recurrent Multi-Layer perceptron (RMLP), Time-Lagged Feed-Forward Networks (TLFN), and conventional Multi-Layer perceptrons (MLP) to forecast seasonal reservoir inflows of the Churchill Falls watershed in northeastern Canada. A climate variability indicator was used as additional information to historical inflow time series in order to predict seasonal reservoir inflows. The prediction results showed that the Bayesian neural network model was best able to capture the additional information provided by the ENSO series, and provided improved predictions in spring and summer seasons relative to the same model using only reservoir inflows. Similarly, time-lagged feed-forward networks and recurrent multi-layer perceptron showed some improved forecast skill in spring when the ENSO index series were used but generally provided superior performance overall. The conventional multi-layer perceptron appears unable to capture relevant information from the ENSO series regardless of the season. However, when only historical flow series are used, all the selected data-driven methods provide very competitive forecast performances.

Mohsen and Zahra (2007) have made a study on the application of ANNs for temperature forecasting. In their study, the application of ANNs to study the design of short-term temperature forecasting (STTF) Systems for Kermanshah city, west of Iran was explored. The important architecture of neural networks, named Multi-Layer Perceptrons (MLP) to model STTF systems, was used. The study based on MLP was trained and tested using ten years' (1996-2006) meteorological data. The results show that MLP network has the minimum forecasting error and can be considered as a good method to model the STTF systems.

Hatim and Aydinko (2008) employed an ANN approach using six variables for the initial prediction of suspended solids in the stream at Mamasin dam.

Huiqun and Ling (2008) have investigated on water quality assessment using ANN. Their paper introduces the ANN and fuzzy logic interface and then uses ANN in the water quality assessment of Dongchang Lake in Liaocheng City.

Sundarambal et al (2008) have made a study on application of ANN for water quality forecasting. In their study, ANN was used to predict and forecast quantitative characteristics of water bodies. The true power and advantage of this method lie in its ability to (1) represent both linear and non-linear relationships and (2) learn these relationships directly from the data being modelled. The study focuses on Singapore coastal waters. The ANN model is built for quick assessment and forecasting of selected water quality variables at any location in the domain of interest. Respective variables measured at other locations serve as the input parameters. The variables of interest are salinity, temperature, dissolved oxygen, and chlorophyll-a. A time lag up to 2Dt appeared to suffice to yield good simulation results. To validate the performance of the trained ANN, it was applied to an unseen data set from a station in the region. The results show the ANN's great potential to simulate water quality variables. Simulation accuracy, measured in the Nash–Sutcliffe coefficient of efficiency (R^2), ranged from 0.8 to 0.9 for the training and over-fitting test data. Thus, a trained ANN model may potentially provide simulated values for desired locations at which measured data are unavailable yet required for water quality models.

Akhtar et al (2009) made a study on river flow forecasting with ANNs using satellite-observed precipitation pre-processed with flow length

and travel time information in Ganges river basin. Their study explores the use of flow length and travel time as a pre-processing step for incorporating spatial precipitation information into ANN models used for river flow forecasting. Spatially distributed precipitation is commonly required when modelling large basins, and it is usually incorporated in distributed physically-based hydrological modelling approaches. However, these modelling approaches are recognised to be quite complex and expensive, especially due to the data collection of multiple inputs and parameters, which vary in space and time. On the other hand, ANN models for flow forecasting are frequently developed only with precipitation and discharge as inputs, usually without taking into consideration the spatial variability of precipitation. Full inclusion of spatially distributed inputs into ANN models still leads to a complex computational process that may not give acceptable results. The pre-processed rainfall was used together with local stream flow measurements of previous days as input to ANN models. A comparative analysis of multiple ANN models with different hydrological pre-processing was presented in their study. The ANN showed its ability to forecast discharges 3 days ahead with an acceptable accuracy. Within this forecast horizon, the influence of the pre-processed rainfall is marginal, because of dominant influence of strongly auto-correlated discharge inputs. For forecast horizons of 7 to 10 days, the influence of the preprocessed rainfall is noticeable, although the overall model performance deteriorates. The incorporation of remote sensing data of spatially distributed precipitation information as pre-processing step showed to be a promising alternative for the setting-up of ANN models for river flow forecasting.

Sreekanth et al (2009) carried out a study on forecasting ground water level with ANNs. The input data for the study were collected from the Maheshwaram watershed, which is situated in the Ranga Reddy District of Andhra Pradesh, India, at a distance of about 35 km from Hyderabad. In their

article, a reliable forecasting model for predicting the groundwater level using weather parameters through ANNs has been developed to have a precision forecasting with added accuracy over the current methods being practiced. The performance of the ANN model, i.e. standard feed-forward neural network trained with Levenberg-Marquardt algorithm, was examined for forecasting groundwater level. The model efficiency and accuracy were measured based on the Root Mean Square Error (RMSE) and regression coefficient (R^2). The model provided the best fit and the predicted trend followed the observed data closely (RMSE = 4.50 and R^2 = 0.93).

Najah et al (2009) carried out a study on prediction of Johor river water quality parameters using ANNs. Johor river basin located in Johor State, Malaysia, which is significantly degrading due to human activities as well as urbanization in and within the area. The study was attempted to predict water quality parameters at Johor River Basin utilizing ANN modelling. Their study proposed a prediction model for total dissolved solids, electrical conductivity, and turbidity. The results show that the proposed ANN prediction model has a great potential to simulate and predict the total dissolved solids, electrical conductivity, and turbidity with absolute mean error 10% for different water bodies.

Holger (2010) has made a detailed review on the methods used for the development of neural networks for the prediction of water resource variables in river systems. In their study, the steps in the development of ANN models are outlined and taxonomies of approaches were introduced for each of the steps. In order to obtain a snapshot of current practice, ANN development methods were assessed based on the taxonomies for 210 journal papers that were published from 1999 to 2007 and focus on the prediction of water resource variables in river systems. The results obtained indicate that the vast majority of studies focus on flow prediction, with very few

applications to water quality. Methods used for determining model inputs, appropriate data sub-sets and the best model structure were generally obtained in an ad-hoc fashion and required further attention. Although multilayer perceptrons are still the most popular model architecture, other model architectures are also used extensively. In relation to model calibration, gradient based methods are used almost exclusively. In conclusion, despite a significant amount of research activity on the use of ANNs for prediction and forecasting of water resources variables in river systems, little of this is focused on methodological issues. Consequently, there is still a need for the development of robust ANN model development approaches.

2.6 INTEGRATED APPROACHES

Many authors have carried out comparison studies between statistical techniques and ANNs. It has been recognized in the literature that regression and neural network methods have become competing model-building methods (Smith and Mason 1997).

Warner and Misra (1996) provide an excellent comparison between regression and neural networks in terms of notation and implementation. They have also underlined the need to understand the potential of neural networks.

Despite the apparent substantive and applied advantages of statistical models, ANN methods have also gained popularity in recent years (Ripley 1994). This method is particularly valuable when the functional relationship between independent and dependent variables are unknown and there are ample training and test data available for the process. ANN models also have high tolerance for noise in the data complexity. Moreover, the software technologies, such as SPSS-Clementine, SAS-Enterprise Minor and

Brian Maker that deploy neural network algorithms have become extremely sophisticated and user-friendly in recent years.

Tam (1991) and Tam and Kiang (1992) compare the machine learning methods and statistical techniques for the data of bank failures in Texas. In this study, neural networks are found to have better predictive accuracy than the other models.

Hruschka (1993) considers the prediction of market response on the basis of data on a consumer brand. It was found that a neural network model with just one hidden unit perform well than linear regression. As there is considerable overlap between the two fields, these two fields may mutually assist each other resulting in better decision making. A research in this direction is the significant aspect of this thesis.

Salchenberger et al (1992) evaluated the ability of a neural network to predict thrift institution failures by comparing it with the best logit model for the data. It is found that the neural networks could achieve better predictive capability than the logit model.

Subramanian et al (1993) compared the performance of neural networks and discriminate analysis for problems of classification that are designed for discriminate analysis approach. Neural networks are found to be comparable but not better than linear discriminate analysis in tow-group tow-variable problems. However, neural networks are found to perform better when either the number of groups or the number of variables increases and also when the classification task tends to become complex.

The issue of sample size is investigated by Patuwo et al (1993) in classification problems where neural networks are found to be comparable to other methods in the training samples but not in the test samples. With an

increase in sample size, the performance of the neural networks is found to improve in the test samples.

Gray and Macdonell (1997) compared various techniques in modelling software metrics based on a number of criteria considered important for the modeling task. This comparison clearly shows that there is no one method, which performs always better than the other methods. An empirical study compares least square regression, robust regression, and neural networks resulting in neural technique outperforming other techniques.

Gorr et al (1994) compared linear regression, stepwise polynomial regression and neural networks for predicting student GPAs in a professional Institute. It was found that though linear regression is the best method overall, none of the methods performs significantly better than the index used by the admissions committee of the Institute.

Hardgrave et al (1994) compare the effectiveness of various statistical procedures and neural networks in predicting the academic success of entering students in an MBA program. They have found that neural networks do not significantly outperform statistical techniques even when the data do not conform to the assumptions required for these statistical techniques.

The problem of predicting bankruptcy filing is considered by Boritz and Kennedy (1995) where neural networks are compared with methods such as discriminate analysis, logit and profit. It is demonstrated that the performance of the neural networks is sensitive to the choice of the variables selected and hence a number of replications may have to be carried out to obtain a reliable measure of model performance.

An exploratory study by Subba Narasimha et al (2000) comparing neural network and regression, when the dependent variable is skewed, indicates results that are favourable to regression.

Shuhui et al (2001) compared regression and neural networks to predict the power produced by wind farms and have found that neural networks perform better than regression models.

Hafizan et al (2004) have made a study on the application of ANN for the prediction of water quality index. This study discusses the development and validation of an ANN model in estimating WQI in the Langat River Basin, Malaysia. The ANN model has been developed and tested using data from 30 monitoring stations. The modelling data was divided into two sets. For the first set, ANN were trained, tested and validated using six independent water quality variables as input parameters. Consequently, Multiple Linear Regression (MLR) was applied to eliminate independent variables that exhibit the lowest contribution in variance. Independent variables that accounted for approximately 71% of the variance in WQI are Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Suspended Solids (SS) and Ammoniacal-Nitrate (AN). The Chemical Oxygen Demand (COD) and pH contributed only 8% and 2% to the variance, respectively. Thus, in the second data set, only four independent variables were used to train, test and validate the ANNs. In their study it was found that the correlation coefficient given by six independent variables (0.92) is only slightly better in estimating WQI compared to four independent variables (0.91) which demonstrates that ANN is capable of estimating WQI with acceptable accuracy when it is trained by eliminating COD and pH as independent variables.

Manoj and Singh (2005) presented a research work on the prediction of mine water quality by physical parameters. Their paper was an attempt to

predict the chemical parameters like sulphate, chlorine, chemical oxygen demand, total dissolved solids and total suspended solids in mine water using ANN by incorporating the pH, temperature and hardness. The prediction by ANN is also compared with Multivariate Regression Analysis (MVRA). For prediction of chemical parameters of mine water, 30 data sets were taken for the training of the network while testing and validation of network was done by 10 data sets with 923 epochs. The predicted results of the chemical parameters of mine water by ANN are very satisfactory and acceptable as compared to MVRA, and seem to be a good alternative for pollutants prediction.

Usha and Kumar (2005) in their study compared the neural networks and regression analysis and concluded that the regression is much better that neural network for skewed data.

Yunchao and Zhongren (2006) have made a research on the integration of ANN with GIS in uncertain model of river water quality. ANN is capable of modelling highly nonlinear relationships and can be trained to accurately generalize when presented with new, unseen data. In previous researches, the ANN models have been used in the prediction of water quality for this reason. However, few of the ANN models have undertaken a research of visually simulated result at present. In their research paper they presented a study, which integrates GIS with the feed-forward back-propagation network (BPN), to create a GIS-BPN-based, visual river water quality uncertain model.

Eddy et al (2007) have used the ANN simulation meta-modelling to assess the groundwater contamination in a road project. It was revealed that the estimation of the extent of a polluted zone after an accidental spill occurred in road transport is essential to assess the risk of water resources

contamination and to design remediation plans. Their study presents a meta-model based on ANN for estimating the depth of the contaminated zone and the volume of pollutant infiltration in a two layer soil (a silty cover layer protecting a chalky aquifer) after a pollutant discharge at the soil surface. The ANN database is generated using USEPA NAPL-Simulator. For each case the extent of contamination is computed as a function of cover layer permeability and thickness, water table depth and soil surface–pollutant contact time. Different feed-forward artificial neural networks with error back-propagation (BPNN) are trained and tested using subsets of the database, and validated on yet another subset. Their performance was compared with a meta-modelling method using multi-linear regression approximation. The proposed ANN meta-model was used to assess the risk for a DNAPL pollution to reach the groundwater resource underneath the road axis of a highway project in the north of France.

Rene and Saidutta (2008) made their study on the title prediction of water quality indices by regression analysis and ANNs. The various wastewater parameters such as TSS, BOD, COD, TOC, and phenol concentration, Alkali Metal Nitrite (AMN), and TDS were obtained from the quality control laboratory of a refinery located in Mangalore, India. Water samples collected from the effluent treatment plant after tertiary treatment were analysed for the parameters considered. Regression analysis for the given data set was carried out using Microsoft Excel and their performance was indicated. The empirical relations developed in this study and the developed ANN based models can be applied with high degree of confidence for refinery wastewater.

Literature points out the modelling capabilities of neural network, some of which are exaggerated and some of which are justified. However, it is evident that this non-traditional modelling method has significant potential

in providing useful predictive models. Hence, it is important to evaluate when and to what extent such a network offers superior performance to standard statistical techniques. Further, many researchers have treated statistical methods and neural networks as competing techniques for data analysis. As there is considerable overlap between the two fields, these two fields may mutually assist each other resulting in better decision making. A research in this direction is the significance of this thesis.

The conventional statistical study was carried out by different researchers throughout the world. But there is a research gaps in comparing the conventional method with the Neural Network model, which will enable the researcher to find the site specific model approach. This study tried to fill the gap between the conventional statistical studies with advanced Neural Network model. In the present study, ANN was used to evaluate the relative effects of various pollution sources on the quality of river water. Using a back propagation algorithm of a feed forward neural network, the relative effects of pollution sources were evaluated for strategic planning of water quality management. Nambiyar basin was selected to demonstrate the procedure and performance of a neural network based approach for analysis and discussion. As of now not much work has been done on the Nambiyar river basin on the water quality assessment and prediction modelling. Similarly there are no studies on the basin to indentify the optimized locations for different usages in the basin. Hence, in this thesis, water quality assessment and predication modelling studies have been carried out in the Nambiyar River basin, Tamil Nadu, India.

CHAPTER 3

METHODOLOGY

3.1 GENERAL

The methodology adopted in this study is discussed in this chapter. To achieve the objective of the study the following integrated approach has been adopted in this thesis.

Rivers have always been the most important fresh water resources, along the banks of which our ancient civilizations have flourished and still most of the developmental activities are dependent upon them. River water finds multiple uses in every sector of development like agriculture, industry, transportation, aquaculture, public water supply, etc. However, since old times, rivers have also been used unfortunately for cleaning and disposal purposes. River water is a very important asset. It supports natural environments, including diverse flora and fauna. It also has an important role in recreational activities and in contributing to overall quality of life. Each river and lake is unique. The size of the drainage basin, the amount of water moving through the system, the proportion of natural versus settled areas, and man's direct impacts are all key factors determining the quality and characteristics of each watershed. Management and protection strategies have to be developed for each water basin individually. There is no single or simple measure of water quality. Surface waters naturally contain a wide variety of substances, and human activities inevitably add to this mixture. Scientists have therefore developed specialized approaches to

measuring quality. A single water sample may be tested for a few substances, or for a few hundred, depending on the issues at hand. With all of the demands humans place on the hydrosphere, as well as climate changes which have led to droughts, the amount of available freshwater is decreasing. In addition, much of the available freshwater is being contaminated with harmful elements such as sulfuric acid, fertilizer, and gasoline. Management of water environments requires an understanding of the impacts on water quality and an understanding of the effectiveness of management actions. Monitoring programs to assess water quality typically aim to assess condition (whether or not water quality meets specified criteria) and trend (whether water quality is getting better or worse).

3.2 HYDRO-GEOCHEMISTRY

The hydro-geochemistry of the study area have carried out to know the possible usage of the Nambiyar River basin and to map the same. The methodology adopted in this study is shown in flow chart Figure 3.1.

3.3 STATISTICAL STUDY

3.3.1 Correlation Coefficient and Linear Regression

Proper management of water resources is very important to meet the increasing demand of water in future. The quality of water is characterized by various physico-chemical parameters. These parameters change widely due to many factors like source of water, type of pollution, seasonal fluctuations, etc. Statistical analysis viz., descriptive statistics, correlation and regression analysis of the physico-chemical properties of a river basin give a fairly good amount of information like their average values and possibly prediction of one variable (usually the one which is difficult to evaluate). Such studies have been carried out by many scholars in the past.

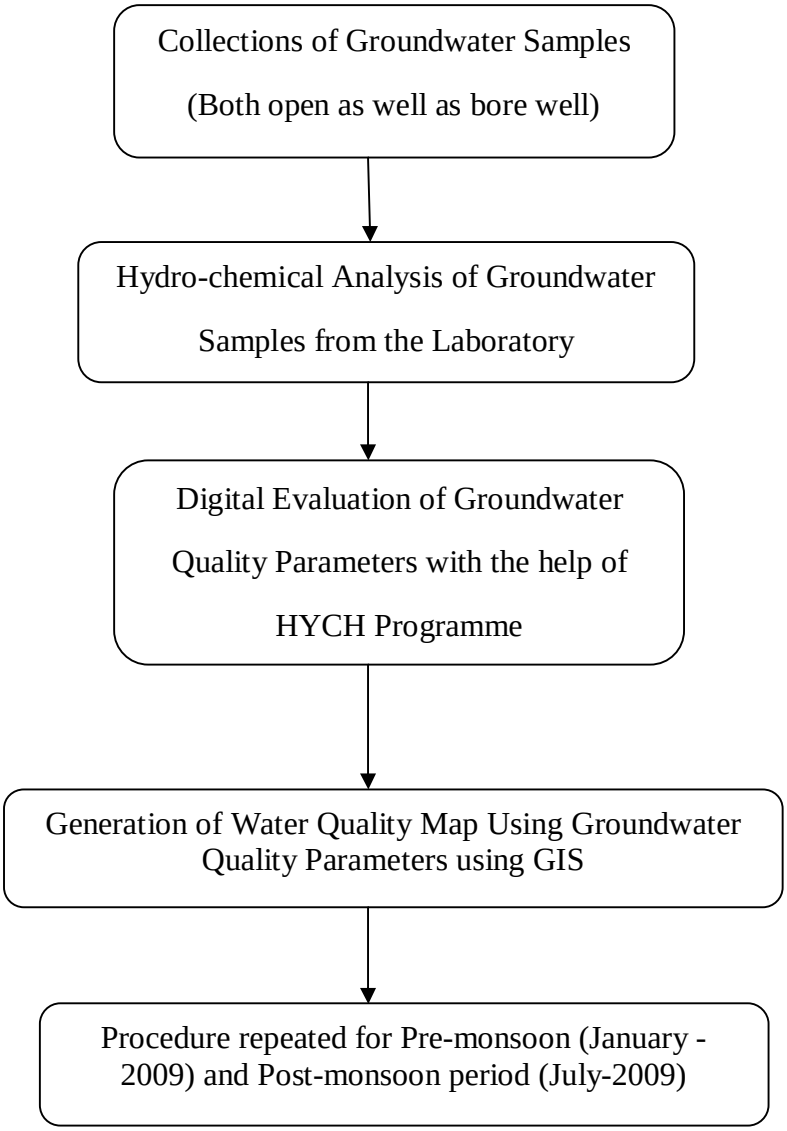

Collections of Groundwater Samples
(Both open as well as bore well)
Hydro-chemical Analysis of Groundwater
Samples from the Laboratory
Digital Evaluation of Groundwater
Quality Parameters with the help of
HYCH Programme
Generation of Water Quality Map Using Groundwater
Quality Parameters using GIS
Procedure repeated for Pre-monsoon (January -
2009) and Post-monsoon period (July-2009)

Figure 3.1 Methodology flow Chart for Hydrochemical Study

Correlation coefficient measures the strength of association between two variables of interest that is whether one variable generally increases as the second increases, whether it decreases as the second increases, or whether their patters of variation are totally unrelated. Correlation measures observe co-variation. It does not provide evidence for causal relationship between two variables. One may cause the other, as precipitation causes runoff. They may also be correlated because both share the same cause, such as two solutes

measured at a variety of times of a variety of locations. Evidence for causation must come from outside the statistical analysis, from the knowledge of the process involved.

Measures of correlation have the characteristics of being dimensionless and scaled to lie in the range $-1 \leq r \leq 1$. When there is no correlation between two variables, $r = 0$. When one variable increases as the second increases, 'r' is positive. When they vary in opposite directions, 'r' is negative. When one variable is a measure of time or location, correlation becomes a test for temporal or spatial trend.

Data may be correlated in either a linear or nonlinear fashion. When 'y' generally increases or decreases as 'x' increases or decreases, the two variables are said to possess a monotonic correlation. This correlation may be nonlinear, with exponential patterns, piecewise linear patterns, or patterns similar to power functions when both variables are non-negative. This non linearity is evidence that a measure of linear correlation would be inappropriate. The strength of a linear measure will be diluted by nonlinearity, resulting in a lower correlation coefficient and less significance than a linear relationship having the same amount of scatter.

The measures of correlation in common use are Kendall's tau, Spearman's rho, and Pearson's r. The first two are based on ranks, and measure all monotonic relationships. The more commonly used Pearson's r is a measure of linear correlation, which is one specific type of monotonic correlation.

3.3.2 Pearson's r

The most commonly used measure of correlation is Pearson's r. It is also called the linear correlation coefficient because 'r' measures the linear

association between two variables. If the data lie exactly along a straight line with positive slope, then r = 1. Correlation coefficient (Pearson ‘r’) has been calculated between each pair of water quality parameters by using Excel spread sheet for the experimental data. Let X and Y are the two variables, then the correlation ‘r’ between the variable X and Y is given by:

$$\text{Correlation (r)} = \frac{\sum (x - \bar{x})(y - \bar{y})}{\sqrt{\sum (x - \bar{x})^2 \sum (y - \bar{y})^2}} \qquad (3.1)$$

Where, $\bar{x}$ and $\bar{y}$ are the sample means. If the values of correlation coefficient ‘r’ between two variables X and Y are fairly large, it implies that these two variables are highly correlated. In such cases it is feasible to try linear relation in the form: Y = Ax + B.

3.3.3 Water Quality Trend Study

The correlation co-efficient ‘r’ will have a value from -1 to 1. Negative sign represents that the two variables do not have similar trend of variation whereas a positive value represents similar trend. More will be the accuracy of fitness if r is more close to unity. Zero value means that there is no relationship between ‘X’ and ‘Y’ and both are independent of each other. Correlation between different pairs of water quality parameters for different water samples, collected at different places of a region provides an idea about the hydrochemistry of the water resources in the region. Statistical approaches have been carried out in this thesis, to assess the water quality trends in the study area.

3.3.3.1 Surface Water Quality Trend

The surface water quality data of Nambiyar River basin from the Tamil Nadu Public Works Department (TNPWD) were used for the study for the years 2002, 2003 and 2004. In this study correlation coefficient among all the surface water quality characteristics were calculated. Linear regression equations were developed for the pair of parameters, which have a significant influence on each other ($r > 8$ with significant 0.01; two tailed and $N = 8$).The correlation analysis on surface water quality parameters revels that all parameters are more or less correlated with each other. The water quality parameters which have $r > 8$ have been used to find regression equations.

3.3.3.2 Groundwater Quality Trend

Similarly the groundwater quality data available with the TNPWD has been used to find the groundwater quality trends in the basin for the years 1998 to 2003.

Apart from this study, samples have been collected from 32 representative wells of the TNPWD. The analyzed groundwater quality data has been used for the statistical study, to find the groundwater quality index of the basin and for ANN model study also.

3.4 WATER QUALITY INDEX

Water being a universal solvent has been and is being utilized by mankind time and again. Of the total amount of global water, only 2.4% is distributed on the main land, of which only a small portion can be utilized as fresh water. The available fresh water to man is hardly 0.3-0.5% of the total water available on the earth and therefore, its judicious use is imperative (Ganesh and Kale 1995). Water is an essential requirement of human and industrial developments and it is one the most delicate part of the environment (Das and Acharya 2003). In the last few decades, there has

been a tremendous increase in the demand for freshwater due to rapid growth of population and the accelerated pace of industrialization (Ramakrishnaiah et al 2009). Human health is threatened by most of the agricultural development activities particularly in relation to excessive application of fertilizers and unsanitary conditions (Okeke and Igboanua 2003). One of the most effective ways to communicate information on environmental trends to policy makers and general public is with indices.

Most of the present day rivers in India are severely polluted due to the irresponsible attitude and mismanagement by the people or stakeholders. Due to economic development, population growth and associated changes of consumption patterns, overuse and pollution of surface water bodies has been increasing, especially in peri-urban and urban areas. Reporting water quality monitoring results in a clear, meaningful way has always presented scientists with a challenge. There is a strong need to develop tools to effectively address the core environmental problems. Water resource professionals generally communicate water quality status and trends in terms of the evaluation of individual water quality variables. While this language is readily understood within the water resources community, it does not readily translate to communities having profound influence on water resources policy, viz, the general public and the policy makers. Political decision-makers, non-technical water mangers, and the general public usually have neither the time nor the training to study and understand a traditional, technical review of water quality data. WQIs are able to facilitate quantification, simplification and communication of complex environmental data. Formulating the WQI was attempted by numerous researchers. The earliest attempt was made by Horton (1965) from selected sewage treatment based on his own judgment and experience. Delphi method developed by “Rand” corporation was an opinion-research technique, Brown et al (1970) used this method to develop a WQI for National Sanitation Foundation (NSF) of USA. Water quality indeed is

contributing for water quality of any water system. It is one of the effective, helpful parameters and provides informative data, which is important to citizens, Government and Public Health authorities. Policies for improvement of water quality program (Singh and Ghosh 1999).

In this thesis WQI for the entire basin has been calculated for the Surface and Groundwater qualities. It is important to note that, prior to this study no significant water quality information (using WQI) was available for Nambiyar basin with a small watershed and for a longer duration for surface water quality and for the groundwater quality also.

3.4.1 GIS Model for WQI

GIS can be a powerful tool for developing solutions for water resources problems for assessing water quality, determining water availability, preventing flooding, understanding the natural environment, and managing water resources on a local or regional scale (Collet 1996). Though there are a number of spatial modelling techniques available with respect to application in GIS, spatial interpolation techniques through Inverse Distance Weighted (IDW) approach has been used in the present study to delineate constituents. This method uses a defined or selected set of sample points and controls the significance of known points upon the interpolated values based upon their distance from the output point thereby generating a surface grid as well as thematic isolines. Important water quality indicating parameters and their distribution patterns were studied in the Nambiyar basin, Tamil Nadu, India. Geo-statistical Analyst provides a cost-effective, logical solution for analyzing a variety of data sets that would otherwise cost an enormous amount of time and money to accomplish. There are two main groups of interpolation techniques, deterministic and geo-statistical. In this study one of the deterministic interpolation techniques called Inverse Distance Weighted

(IDW) has been used. The geo-statistical interpolation techniques are based on statistics and are used for more advanced prediction surface modeling. The methodology adopted for the WQI study is given in Figure 3.2.

GIS is gaining importance and widespread acceptance as a tool for decision making or support in the infrastructure, water resources, environmental management, spatial analysis and urban regional development planning. With the development of GIS, environmental and natural resources management has found information systems in which data are more readily accessible, more easily combined and more flexibly modified to meet the needs of environmental and natural resources decision making. In this study, GIS was extensively used to identify the zones of suitable water quality in the Nambiyar watershed based on the sampled data.

3.5 INTELLIGENT PREDICTIVE MODEL STUDY

3.5.1 Neural Network Model

A neural network consists of a set of interconnected individual neurons organized into several layers, the first layer being the input layer, which produces the network output. Numerical data moves from connection to each unit whereupon it is processed. Processing takes place locally at each unit and between connections in a parallel fashion.

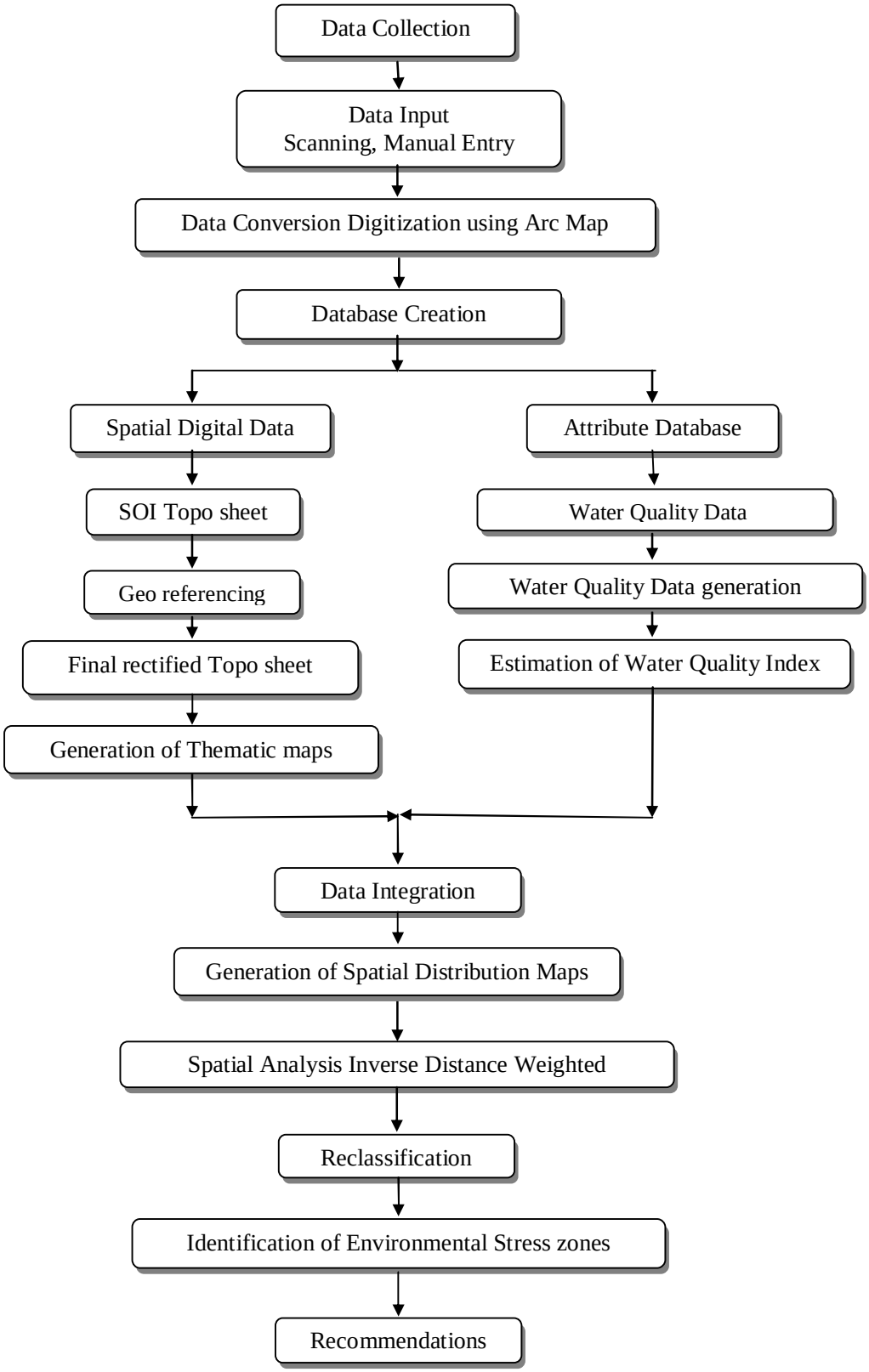


Figure 3.2 Methodology flow Chart for WQI Study

The total data of 3210 samples of 30 sample locations were divided into a training set consisting of 1926 samples (60% of the total samples), the remaining 642 samples (20% of the total samples) were used for validation and the remaining 642 samples (20% of the total samples) were used for testing. Mat lab Neural Network tool has been used to run the model. The standard two layer feed forward neural network trained with Levenberg-Marquardt method has been used in this modelling.

3.5.2 GIS Integration

ANN when coupled with GIS can be used for many applications for the purpose of improved decision-making. GIS information can become increasingly more valuable for decision making when coupled with artificial intelligence (AI). When linked with GIS, artificial intelligence can be useful for evaluating monitoring and decision making. Spatial model with GIS is a proven method that has been well documented in many deterministic models studies. The databases of the model contain two types of data, viz. spatial data and attribute data. The spatial data include Arc View shape files mainly representing the 32 measured points of Nambiyar river basin. The attribute data describe the features of the sample points, viz. the concentration of TDS, EC, Cl, Mg and Hardness.

CHAPTER 4

STUDY AREA

4.1 GENERAL

The earth is known as the “Blue Planet” or “Water planet”. The presence of water makes it unique and is the sole basis for the sustenance of life on the earth. About 70.7% of the earth is covered by water and the remaining is land. However, out of this vast coverage of water only 1% is available for human consumption. The remaining 97% of water is in the ocean and 2% in the Polar Regions in the form of glaciers. The 1% consumable quality of water is available on the surface of the earth as well as underground. In Tamil Nadu nearly 98% of the surface water resources and 73% of ground water resources have been exhausted. Unless it is better planned to harness, to conserve, manage and utilize the water resources, it is going to be a severe crisis for water. There are 34 river basins in Tamil Nadu, India. For the purpose of taking up micro-level hydrological studies and water resources planning activities, the 34 river basins are grouped into 17 major river basins by the Public Works Department, of the Tamil Nadu State Government. Nambiyar river basin is one among them. The Nambiyar basin falls in Tirunelveli and Thoothukudi districts. There are three rivers in this basin. The Karamaniyar is in the northern part of the basin and Hanumanadhi River is in the southern part of the basin and the Nambiyar River is in between these two rivers. Tamiraparani basin on north and Kodaiyar basin on south and the Gulf of Mannar on the east surround this basin. The Nambiyar river basin falls in part of the Survey of India toposheets 58H and 58L and it

lies between the following co-ordinates: North- Latitudes 08° 08’00” - 08° 33’ 00” and East - Longitude 77° 28’00” - 78° 15’ 00”. This basin is sandwiched between Tamiraparani basin on the north and Kodayar basin on the west. The total area of the basin is 2084 sq.km and it covers part of Tirunelveli and Thoothukudi districts.

4.2 PHYSIOGRAPHY

Physiographically, Nambiyar basin is divided into western hilly region and eastern plain undulating topography. Western hilly region extends from Agsthayarmalai in the north and Kanyakumari town in the south and it acts as the western boundary of the basin. All the rivers flow from the eastern slope of the Western Ghats at various altitudes.

A stream from the east of Kalakkadu village joins the Manimuthar main canal and surplus from Vijayanarayanam tank forms the Karamaniyar River. Numerous streams in the downstream join the river Karamaniyar. Its width is increasing from Sathankulam till its end.

The river Nambiyar originates in the eastern slopes of the Western Ghats near Nalikkal Mottai about 9.6 km west of Thirukkarangudi village at an altitude of about 1646 m above MSL. Kalankal odai is a tributary of Nambiyar River which originates near Kannanallur area, after traversing 6.5 km and finally it joins Nambiyar at 37th km near Kovankulam.

Hanumanadhi originates in the eastern slopes of the Western Ghats at an altitude of 1100 m above MSL in the Mahendragiri hill region. Uppar River originates in the eastern slopes of the Western Ghats near Takkumalai east forest at an altitude of about 808 m above MSL.

The elevation of the Western Ghats, ranging from +300 m to +1200 m above MSL, is in this basin area. There are several peaks which are raised above +1000m. MSL. They are Kaniyini mottai 1663 m, Mahendragiri hills 1657 m, Kottankaitatti mottai 1530 m and Thiruvannamalai hills 1402 m.

The eastern plain is an undulating topography with its elevation varying from +100 m to +15 m. All the rivers starting in the Western Ghats regions flow in the plains towards east, southeast and south directions. There are two reservoirs in the Nambiyar basin, the first one is Namibiyar and the other, Kodumudiyar. There is one big tank located at Vijayanarayanam village called Vijayanarayanam Lake.

In the eastern part of the basin, two patches of sand dunes are noticed and they are deposited by wind action. These sands are reddish white in colour and they are locally called “Teri sands”. One patch of Teri sand dunes occurs north of Tisaiyanvilai called Ittamalai Teri, and another one which occurs at the northeast of Sattankulam, called Kudiramoli Teri, with considerable thickness ranging from 20 to 30 m above ground level. Ittamalai Teri rises above 60 m from MSL.

4.3 DRAINAGE

Nambiyar river basin is constituted by rivers like Nambiyar, Karamaniyar, and Hanumanadhi. Nambiyar and Hanumanadhi originate in the eastern slopes of the Western Ghats at an altitude of about 1000 m MSL. Karamaniyar River originates from the surplus water from Vijayanarayanan tank of about 100 m. The watershed area comprises the hilly region of Mavadirottai, Kakamunikal mottai, Thiruvannamalai and Mahendragiri hills.

4.4 SUB-BASINS DESCRIPTION

4.4.1 Karamaniyar River

It has a number of small seasonal streams and gets its flows mainly from the surpluses of Vijayanarayanan tank and from monsoon rainfall. Manimuthar main canal joins the river near Pillaikulam village. After traversing a total distance of 56.5 km, the Karamaniyar River flows into the Gulf of Mannar near Manapadu village in Tirunelveli District. The Karamaniyar River feeds about 75 tanks and has a registered ayacut of 2976 hectares. The total extent of this sub-basin is 903.93 sq.km, Covering blocks of Alwarthirunagari, Tiruchendur, Sathankulam, Udankudi, Kalakkadu, Nanguneri and Radhapuram either in part or full.

4.4.2 Nambiyar River

Nambiyar River originates in the eastern slopes of the Western Ghats near Nalikkal Mottai about 9.6 km west of Thirukkarangudi village at an altitude of about 1060 m. This river is constituted by three branches of seasonal streams, like Tamaraiar, Kombaiar and Kodumudiar. Kombaiyar and Kodumudiyar originate at the eastern slope of the Western Ghats at an altitude of about 1600 m. near Mahendragiri hills. Nambiyar then takes an easterly course up to the Tirunelveli-Nagercoil trunk road crossing and flows in a south-easterly direction. Parattaiyar originates in the eastern slopes of the Western Ghats at an altitude of about 1200 m. near Kakamunjikai Mottai and joins another arm of Nambiyar at the foot of the hills. After feeding a number of small tanks, this finally joins with Nambiyar again near Ervadi at 18.5 km.

Kalankal odai is another tributary which originates near Kannallur area in Nanguneri taluk of Tirunelveli District. It gets flows from the

surpluses of a few tanks dependent on other streams. After traversing a distance of 6.5 km, it finally joins with the Nambiyar near Kovankulam.

Another tributary which originates near Vadakku Valliyur area in Nanguneri taluk of Tirunelveli district at an altitude about 90 m gets flows from the surpluses of small tanks dependent on other streams. After traversing a distance of 10.5 km finally the tributary joins Nambiyar near Sankarapuram village. Finally the Nambiyar River flows into the Gulf of Mannar after traversing a total distance of 59 km from the origin.

The Nambiyar River has a total of 9 small anicuts, viz. 1. Mailannani anicut, Dalavaipuram anicut, 3. Rajakkamangalam anicut, 4. Malapudur anicut 5. Kannanallur anicut, 6. Vijayan anicut, 7. Kovankulam anicut, 8. Islapuram anicut, and 9. Pulimangalam anicut. The total extent of this sub-basin is 604.32 sq.km.

4.4.3 Hanumanadhi River

Hanumanadhi originates in the eastern slopes of the Western Ghats at an altitude of 1100 m in the Mahendragiri hill region on the North West of Panakkudi village in Nanguneri Taluk of Tirunelveli District. It has a number of jungle streams. After feeding a few tanks, they join Hanumanadhi River at various points. It flows in the hill ranges for about 5.6 km and reaches 6.4 km west of Panakkudi village in Nanguneri taluk. It traverses entirely in Nanguneri taluk for a distance of about 32 km and flows into the Gulf of Mannar. There are 11 small anicuts across this river viz. 1. Sivanpilli anicut, 2.Senthilkathayan anicut, 3.Thandayarkulam anicut, 4. Sanjetti anicut, 5. Perungudi anicut, 6. Vadakkankulam anicut, 7. Adankarkulam anicut, 8. Sakkilianparai anicut, 9. Kanjaneri anicut, 10. Alaganeri anicut, and 11.Koliankulam anicut. The total area of the sub-basin is 510.179 sq.km

covering blocks of Kalakkadu, Valliyur, Radhapuram in Tirunelveli District and Thoothukudi District either in part or full.

4.5 RELIEF

The highest elevation of different ranges, 1657 m, 1585 m and 1530 m are found in Kalakkadu reserved forest, Mahendragiri Reserved forest and the minimum elevation is 500 m at the foot hills at the western part of this basin. Adjacent to this hill ranges, the 100 m contour runs across this basin from north to south.

The remaining part of the basin is generally a plain terrain with gentle slope towards south and east. There is a sand dune namely ‘Teri sand’ in the south of Sattankulam having an elevation of 67 m. There is also a similar type of structure in and around the villages Kuttam and Uvari in the south of Thisaiyanvilai.

The river Karamaniyar flows in the basin at the eastern part of the basin from northwest to southeast, passing through Sattankulam and confluences with Gulf of Mannar at Kulasekaranpattinam.

Nambiyar River originates at an elevation of 1479 m in Nalikkal Mottai with Kallakadu reserved forest. It traverses through Pudukulam, Pettaikulam and confluences in Gulf of Mannar at Thiruvambalampula.

The river Hanumanadhi originates at an elevation of 1100 m in Mahendragiri reserved forest. It traverses through Panakkudi, Vadakankulam and finally confluences with the Gulf of Mannar at the south of Erukkamkulam.

4.6 GEOLOGY

The various rock types exposed and the structural details of Nambiyar river basin were collected from the Geological Survey of India. The basin area comprises of rocks of Khondalite and Charnockite groups of Archaean age in major part of the area. Migmatite gneiss of Archaean age also occurs in the plains. The coastal plains host rocks of Misocene, of quaternary and recent age.

The Khondalite group consists of Garnet-biotite sillimanite gneiss with or without graphite. It consists of sheets of sillimanite needles, biotite, occasional lenses of graphite with red and pink garnet. These rocks exhibit fine foliation and perfect parallel banding. Influx of granitic material has resulted in the formation of quartzo-feldspathic gneiss in many places.

Charnockite occurs mostly as concordant bands and lenses of varied dimensions in association with Khondalite with diffused contacts. It grades into gneiss and vice versa both along and across the strike. Generally, it is garnetiferous near the contact with gneiss and non-garnetiferous in the middle portion. The rocks show granblastic texture and are mostly intermediate to acidic.

The Migmatite complex consists of granite gneiss. The rocks of the Migmatite group are widely distributed and interlayed with Charnockite in the central and southern part of the area. Garnet-biotite gneiss occurs as bands and lenses and stands out as raised ridges. It is characterised by the presence of biotite foliae and concentration of garnet in layers. At places, the garnet, biotite gneiss also carries segregations of graphite flacks.

In the eastern part of the basin, a few outcrops of hard marine sand stone and shell limestone with intercalations of pebble beds of miocene age,

unconformably overlie the rocks of the Archaean age. The pebble bed consists of angular to sub-angular and coarse fragments of quartz, in a matrix of ferruginous clay. The formation comprising of hard sandstone and calcareous shelly limestones are encountered north of Sattankulam. Tisaiyanvilai called as Panambarai sandstone are equivalent of Cuddalore sandstone formation. The sandstone is seen as patches extending from southwest to northeast direction parallel to the coast. The shell limestone is compact and consists of corals and shells of gastropods and are embedded in a fine grained calcareous matrix.

Quaternary grit, sandstone and shell limestone overlie the Miocene rocks with a distinct unconformity marked by a bed of conglomerates in the southeastern corner of Nanguneri taluk.

Kankar and tuffaceous limestone of recent age occur along the nallahs of the Karamaniyar, Nambiyar and its tributaries over a width of 200m to 300m and extends over a length of 6 km and more. It is generally hard, massive and shows a modular structure.

In the southeastern part of the basin, beyond Sattankulam and Tisayanvilai, recent to sub-recent quaternary alluvial plains extend with isolated friable sandstone and shell limestone. Teri sands occur north of Tisaiyanvilai (Ittamali Teri) and Northeast of Sattankulam (Kudiramoli Teri) with considerable thickness ranging from 20 to 35 m. These are reddish in colour and medium to coarse grained.

4.7 HYDRO-GEOLOGY

In hard rocks, weathered zone exists up to 25 mbgl underlain by fractures up to 30 mbgl as per lithology of boreholes. In Nanguneri, Vadaku Valliyur and Vijaynarayanapuram areas the yield of the bore wells range from

45 to 295 lpm. Transmissivity of the aquifer is 10-20 m^2/day. Weathered zones exist up to 20 mbgl. followed by fractures up to 40 mbgl. Yield of the bore wells in this area range from 25 to 100 lpm. Transmissivity of the formation vary from 5-10 m^2/day. In the western part of the basin (Panagudi and Radhapuram areas) weathered mantle persist from 30-45 mbgl and fractures continue up to 50 mbgl. The yield of the boreholes ranges from 15 to 80 lpm. Transmissivity of the aquifer is from 2 to 40m^2/day. In the southern part of the basin, south of Radhapuram and Kudankulam, the weathered zone exists 15-25 mbgl and fractures continue up to 30 mbgl. Transmissivity of the aquifer in this region is 2 to 30 m^2/day. In the southern part of the basin near Kudangulam, sandstone occurs up to 15 mbgl underlain by gneisses. In coastal alluvium, south and southeast of Tisaiyanvilai, sandstone is encountered up to 33 mbgl near Nadaruvari and it goes up to 90 mbgl near Pailanthuruvai underlain by gneisses. In Kundal area sandstone content is up to 120 mgbl with intervening limestone and clay. Water level is at 26 mbgl. and the yield is 583 lpm. The transmiisivity of the aquifer is 43m^2/day. Specific conductance of groundwater is 655 microsiemens. In general yield of bore wells in Teri sands in sedimentary formations range from 200 to 1950 lpm and in Tertiary sandstones in coastal alluvium area ranges from 75 to 1045 lpm. In hard rocks, the yield of the boreholes range from 45 to 295 lpm.

4.8 INDUSTRIES

4.8.1 Power Generation

There is no power project (Thermal or Hydro Power) situated in this basin. Power is being distributed through southern grid. There is no scope for further development.

4.8.2 Major Industries

Palmyra industry exists in many places. The cottage industries include be-keeping, artificial flowers making, cane furniture making, wood turning industry, tailoring etc., and safety matches are made in many places. Handloom weaving, beedi rolling and net weaving are predominant in some places. Cotton, yarn and textiles are the main items produced by the large-scale industries. Seyed Cotton Mills is a medium scale industry with 224 workers. Sundaram Textile Limited is a spinning factory manufacturing cotton yarn. The factory provides employment to 400 persons.

4.8.3 Mineral-Based Industry

Limestone, Kankar, Garnet and Limonite are available in large quantities. There are number of stone crushers which use the stones for making jellies. There are also bricks and tiles industries, which use earth for making bricks and tiles. Granites which are used for polishing are found in many places. Beedi manufacturing is an important industry. Every village has small factories where beedies are made.

4.8.4 Garnet Industry

A group of complex silicate minerals by name Garnet have physical properties of isometric crystal formula and general chemical formula. The beech area of Radhapuram taluk contains a variety of garnets, which is used in industries as almandite, the occurrence of which here, is commercially attractive. The garnet is collected under mining leases. V.V. Minerals is one of the important garnet industries in the basin. Nanguneri taluk under the basin has been selected for intensive development of rural industries. The Government of Tamil Nadu is conducting many schemes to improve the status of the people.

4.9 NON-CONVENTIONAL ENERGY RESOURCES

A highly favourable wind for six months during South West monsoon is a good source of power. Similarly there is moderate wind during North East monsoon. Prior to 1990, the industries in India, and in particular Tamil Nadu, registered deceleration and there was a setback in the industrial growth all over India.

4.10 IMPACT OF INDUSTRIES IN THE BASIN

Most of the industries in the basin are medium or small scale industries. The raw materials used in various industries are cotton, coconut waste, seeds for oil, latex, lime stone, wood, sand, milk flour and polythene etc., The source of water for most of the industries is only groundwater through bore wells. The industrial water supply requirement for the basin area was calculated by Public Works Department, Government of Tamil Nadu, as 1.8314 MCM in 1994. The demand projection has been calculated by TNPWD and the data is given below.

Year	Water demand in MCM
2019	5.4990
2044	9.1500

Due to over extraction of ground water, the water table is considerably lowered. Large number of mining industries causes geomorphologic changes which also may be a reason for runoff. There are no direct entry points of pollution from the industries to the rivers, channels and tanks. It has been observed that no hazardous chemicals or effluents are discharged in rivers or channels or tanks. Most of the industries do not have proper effluent treatment facilities. The only possible pollution is the dust

pollution due to many crusher mills, lime stone and blue metal industries. This leads to bronchial diseases. Women and children are involved in beedi industries which pose the major problem of health of the people.

4.11 DISEASE / HEALTH HAZARDS

The predominant places for kidney disorders are Uvari, Tissayanvilai, Radhapuram, Chettikulam, Therkukallikulam, Moolakaraipatti, Ittamoli and Munanjipatti. There is no report of epidemic in the basin area. Seasonal fever and diarrhea are reported in many villages. The reason for kidney disorder is due to the salinity of ground water in this area. This is also because of lack of rainfall, scarcity of water and sea water intrusion. Skin related diseases are often reported because of the poor quality of water, water logging, poor drainage and sanitary facilities. Thyroid disease due to iodine deficiency has also been reported in many villages such as Sattankulam, Udankudi etc., Because of the above mentioned reasons and lesser chances for agricultural labour, people started migrating to major cities like Mumbai, Chennai etc., and the rate of migration is very high in this area.

CHAPTER 5

HYDRO-GEOCHEMISTRY

5.1 INTRODUCTION

The groundwater flows slowly through the rocks and it dissolves many minerals from the bedrock. The slow percolation of water results in a prolonged contact through the minerals. Many minerals are dissolved by the groundwater as it passes over them and in time quasi-chemical equilibrium can be reached between the groundwater and the minerals. By this process the groundwater gets saturated by certain dissolved solids. The ability to dissolve the mineral constituents determines the chemical nature of groundwater. The geochemistry of groundwater is an important topic after the publication of the work done by Back and Hanshaw (1965). The purpose of this study is for the better understanding of the chemical reaction between groundwater and earth materials and to explain the process by which water attains its observed chemical character. Groundwater is not pure. It usually contains some amount of dissolved mineral ions. The amount of ions, concentration and the type of ion will determine the usage of the water for various purposes.

The geochemical study of the groundwater is important with respect to the water use. This study gives better understanding about the quality and development process taking place in the area, which can provide information about the limits of total development or permit planning for appropriate treatment that may be required as the results of future changes in the quality of water supply.

Groundwater chemistry changes, as the water flows in the underground environment, by the increase of dissolved solids and major ions (Chebotarev 1955). Longer the duration the groundwater staying in the ground, poorer will be the quality. The chemistry of the coastal aquifers is complex due to the threat of groundwater contamination by seawater (Radha Krishna 1971, Balasubramanian and Sastri 1985, Lawrence 1995). The quality of the ground water mainly depends on the quality of cations and anions existing in it. The reasons for groundwater deteriorations are:

- Discharge of industrial effluents,
- Discharge of sewage,
- Saline water intrusion along the coastal regions,
- Rock-water interaction in aquifer,
- Microbial activities in bio-films in underground,
- The hydrodynamic and dilution properties of aquifers and
- The intensity of pollution.

All these parameters and their influences on groundwater system must be considered from a long-term point of view, in order to protect the existing groundwater resources. As the ground water moves from the recharge area to the discharge area, the chemistry is affected by variety of geochemical processes. The dissolved components of water not only undergo changes during transport, but also react and redistribute the mass among various ions. With increase in the demands of groundwater in many coastal areas due to exponential growth of population and other needs, the base flow is decreased or even reversed, causing seawater intrusion. There are several other factors that contaminate groundwater and a few of them are:

- Excess usage of fertilizer in agricultural activities,
- Extensive aquaculture in coastal environments and
- Salt pan industries

Hem (1991) and Prakasa Rao (1997) have stated that once the interrelated hydro-geochemical process, which causes significant variations in groundwater, is evaluated; it would be easier for administrators to take necessary steps to maintain quality control/improve and also to suggest an alternative water supply schemes.

5.2 GROUNDWATER SAMPLING AND CHEMICAL ANALYSIS

Groundwater samples have been systematically collected from 32 locations as shown in Figure 5.1 and Table 5.1, for both pre and post-monsoon periods, from the existing open and bore wells in January 2009 and July 2009 following the standard sampling procedure given by Palmquist (1973). All the samples have been analyzed for major cations and anions viz. EC, pH, TDS, Ca, Mg, Na, K, HCO_3, CO_3, Cl, and SO_4 using the standard method prescribed by APHA-AWWA and WPCF(1984). The results of the chemical analysis of groundwater in Nambiyar River basin for both pre and post-monsoon periods have been given in Table 5.2 and 5.3 respectively.

5.3 CHEMICAL QUALITY

Chemical analysis forms the basis of interpretation of quality of water in relation to source, geology, climate and use (Raghunath 1987). Water being the universal solvent, it is important to know the geochemistry of the dissolved constituents.

5.3.1 Units of Measurement

The mineral concentrations in water are referred as total dissolved solids (TDS). The common measured unit of this is in parts per million (ppm) or mg/l. The dissolved concentration of inorganic salts also present, hence the term “salinity” is described in SI system. The mass concentration of dissolved solids in any liquid is given in terms of kilograms per cubic meter (kg/cu.m).

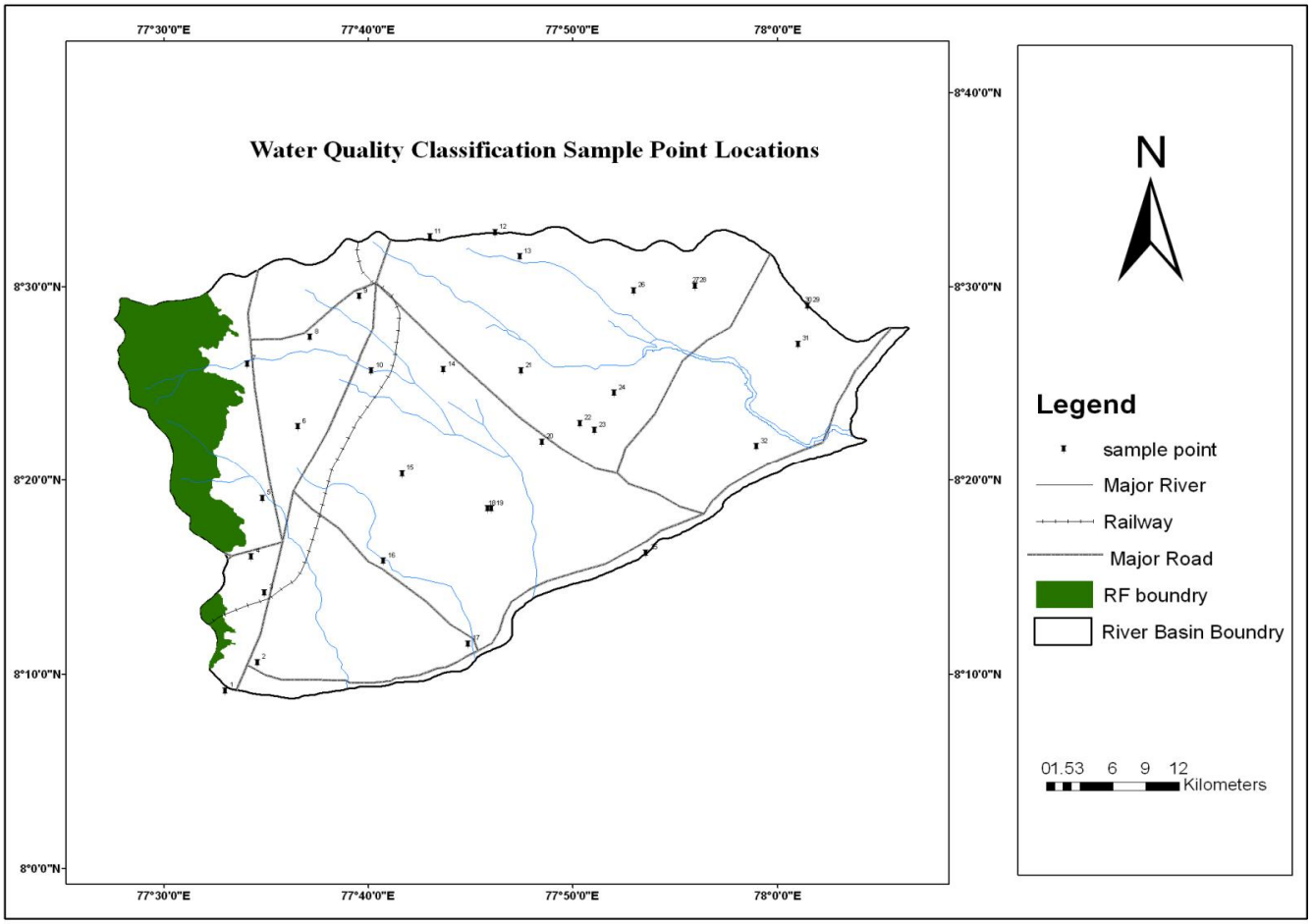


Figure 5.1 Water Quality Classification Sample Point Location Map

Table 5.1 Sample Points Location ID Details

Station Name	ID	Station Name	ID
Bagavathipuram	1	Vijayapathi	17
Karunkulam	2	Kausturirangapuram	18
Soundaralingapuram	3	Kasturirangapuram (a)	19
Kavalkinar	4	Mannarpuram vilakku	20
Panagudi	5	Vadakku Vijayanarayanam	21
Valliyoor	6	Ittamozhipudur	22
Tirukkurungudi	7	Ittamozhi	23
Alangulam	8	Pudukulam	24
Nanguneri	9	Uvari	25
Tulukkarpatti	10	Karunkadal	26
Unnankulam	11	Anandapuram	27
Moolaikaraipatti	12	Ananda_puram	28
Munanjipatti	13	Tiruchendur	29
Parappadi	14	Sundarapuram	30
Samugarengapuram	15	Udankudi	31
Radhapuram	16	Padukkapathu	32

Table 5.2 Groundwater Quality Analysis Results in Pre-Monsoon Period

Sl. No.	Location	EC	pH	TDS	Hardness	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO_3^{-}	CO_3^{++}	Cl^{-}	SO_4^{-}	NO_3^{-}
		µS/cm		ppm										
1.	Alangulam	610	8	369	125	34	9.72	90	3	173.32	1.63	64	37	5
2.	Anandapuram	1090	8.2	609	380	106	27.95	74	4	213.50	0	199	37	12
3.	Anandapuram(a)	1800	8.2	1076	350	140	72.90	115	4	122.00	0	383	89	48
4.	Bagavathipuram	340	8.2	189	120	22	15.80	28	2	132.94	1.98	18	8	3
5.	Ittamozhi	3840	8	2294	120	216	160.38	336	2	286.70	0	851	158	97
6.	Ittamozhipudur	1950	8	1169	450	116	38.88	230	29	225.70	0	390	91	36
7.	Karunkadal	640	8.2	352	145	14	26.73	76	22	231.47	3.45	64	4	0.05
8.	Karunkulam	2530	8.3	1421	355	148	118.00	193	8	305.00	66	496	115	28
9.	Kasturirangapuram (a)	4220	7.6	2503	112	320	77.76	469	9	152.50	0	1170	326	12
10.	Kausturirangapuram	5540	7.9	2393	160	400	184.68	506	11	91.50	0	1489	230	119
11.	Kavalkinar	820	8.2	1305	320	122	60	235	10	212	0	103	101	1
12.	Mannarpuram vilakku	890	8	527	245	54	26.73	90	3	122.00	0	181	43	15
13.	Moolaikaraipatti	2380	8	1321	480	92	85.05	281	2	146.40	0	638	110	9
14.	Munanjipatti	10110	7.2	2531	470	720	204.70	276	29	457.50	0	3332	221	4
15.	Nanguneri	1300	8	740	275	68	25.52	166	14	219.60	0	255	62	9
16.	Padukkapathu	4000	9	2354	470	80	66.00	690	26	159.00	18	1191	158	10

Table 5.2 (Continued)

17.	Panagudi	410	8.4	227	160	36	17.01	20	2	136.65	3.23	25	13	7
18.	Parappadi	1170	7.5	641	350	90	30.38	115	2	274.50	0	223	22	5
19.	Pudukulam	2750	7.8	1700	370	140	77.76	322	33	274.50	0	567	168	57
20.	Radhapuram	2300	8	1362	300	112	53.46	299	7	201.30	0	560	144	20
21.	Samugarengapuram	1600	8.2	963	380	68	51.03	189	6	183.00	0	291	96	39
22.	Soundaralingapuram	570	8.4	321	160	26	23.09	55	3	136.65	3.23	67	12	11
23.	Sundarapuram	5400	8.1	3260	375	130	157.95	782	6	237.90	0	1595	365	24
24.	Tiruchendur	2650	8.6	1482	240	80	9.72	483	21	732.00	84	347	57	5
25.	Tirukkurungudi	870	8.4	475	145	16	25.52	131	1	253.88	5.99	92	42	2
26.	Tulukkarpatti	470	8.1	274	165	34	19.44	30	2	88.89	1.05	60	13	14
27.	Udankudi	4600	8.1	2757	104	160	155.52	621	23	317.20	0	1276	317	11
28.	Unnankulam	690	7.5	377	180	50	13.37	76	3	209.36	0.62	46	37	5
29.	Uvari	3020	7.8	1778	360	184	48.60	368	41	353.80	0	737	144	18
30.	Vadakku Vijayanarayanam	200	8	119	50	14	3.65	23	3	49.48	0.47	25	6	3
31.	Valliyoor	970	7.8	573	170	34	20.66	138	8	225.70	0	142	49	15
32.	Vijayapathi	2900	8	1607	320	220	89.91	244	11	91.50	0	893	77	6

Table 5.3 Groundwater Quality Analysis Result in Post-Monsoon Period

Sl. No.	Location	EC	pH	TDS	Hardness	Ca	Mg	Na	K	HCO_3	CO_3	Cl	SO_4	NO_3
		µS/cm		ppm										
1.	Alangulam	630	8.8	407	170	22	28	92	3	189	42	82	18	6
2.	Anandapuram	1600	8	1036	435	88	52	207	7	201	0	397	110	17
3.	Anandapuram(a)	580	8.5	361	220	36	32	46	5	134	24	82	19	11
4.	Bagavathipuram	256	8.4	256	490	40	90	23	12	92	24	82	10	0
5.	Ittamozhi	1760	8	918	365	60	125	83	25	110	0	471	91	2
6.	Ittamozhipudur	1850	8.1	1148	410	80	51	207	78	171	0	432	115	22
7.	Karunkadal	2000	7.7	1314	300	176	63	196	10	262	0	440	211	20
8.	Karunkulam	900	9.2	551	245	42	34	117	2	311	24	106	32	9
9.	Kasturirangapuram (a)	3700	8.9	2294	114	280	107	391	23	122	18	1134	230	11
10.	Kausturirangapuram	2300	8.1	1450	410	28	131	311	20	122	0	744	144	2
11.	Kavalkinar	1900	8	1230	310	68	34	345	11	567	0	319	82	20
12.	Mannarpuram vilakku	830	9.5	565	260	52	32	104	5	165	24	131	86	11
13.	Moolaikaraipatti	2300	9.1	1375	440	152	63	242	13	214	24	532	118	28
14.	Munanjipatti	530	9.3	318	180	52	12	46	7	128	24	89	15	2
15.	Nanguneri	200	8.6	141	85	22	7	18	3	73	12	18	12	3
16.	Padukkapathu	3700	8.7	2447	540	64	92	690	74	512	90	900	269	3

Table 5.3 (Continued)

17.	Panagudi	4400	7.9	2932	116	296	102	483	117	354	0	978	221	126
18.	Parappadi	180	8.5	115	80	24	5	9	3	49	12	18	12	2
19.	Pudukulam	1100	7.9	600	290	58	34.8	138	6	106.75	0	199	29	28
20.	Radhapuram	2500	7.8	1531	320	104	88	334	20	372	0	624	156	4
21.	Samugarengapuram	2200	9.2	1473	360	152	68	253	18	268	30	440	130	56
22.	Soundaralingapuram	5010	7.8	2685	180	140	353	327	25	317	0	1453	226	0
23.	Sundarapuram	350	8.7	186	165	26	24	5	6	79	30	39	7	2
24.	Tiruchendur	1900	8.8	1072	320	24	63	299	19	421	78	362	7	2
25.	Tirukkurungudi	320	7.9	218	180	18	33	14	3	171	0	43	10	2
26.	Tulukkarpatti	1490	8.7	817	250	24	46	221	9	128	42	393	7	2
27.	Udankudi	3200	8.1	2048	101	168	143	334	33	104	0	1014	106	45
28.	Unnankulam	1550	9.4	963	170	32	22	311	6	403	12	323	44	2
29.	Uvari	910	8.6	557	275	46	39	81	26	189	24	131	34	18
30.	Vadakku Vijayanarayanam	6000	8	3737	128	112	243	874	37	201	0	1787	298	64
31.	Valliyoor	4200	7.9	2988	102	296	68	575	70	342	0	936	202	151
32.	Vijayapathi	890	9.5	582	260	66	23	92	30	153	42	131	34	20

The ‘mg/l’ is the common unit used to represent mostly because it is more accurate and numerically equal to the ‘ppm’ units for high quality fresh water. For most of the practical purposes, water with less than about 10,000 mg/l TDS and at temperature below 212^{o}F (100^{o}C) can be considered to have a density sufficiently close to 1kg/l so that 1 mg/l equal to 1ppm (Freeze and Cherry, 1979). When water has a higher salinity or temperature, the equivalence between 1 mg/1 and 1 ppm no longer holds and hence density corrections must be made. For an understanding of many geochemical problems, expressions of analytical results by the above said weight-volume methods are not adequate in as much as the combination and dissociation of cations and anions are governed by their equivalent Weights (combined weights) rather than their gravimetric weights. The equivalent weight of an ion equals its atomic or molecular weight divided by its valency.

5.3.2 Physical Parameters

The physical parameters of the groundwater are very important for a better understanding of the geochemistry of groundwater of the study area. Unlike surface water, groundwater is generally clean, colourless and odourless with little or no suspended matter and at relatively constant temperature. It is necessary to assess the physical quality of water in addition to the chemical quality.

Some of the principal hydro-geological and environmental factors influencing the physical quality of groundwater are as follows:

5.3.3 Colour

Water used for drinking purposes should be free of colour, objectionable, odours and turbidity. The presence of organic matter and iron may impart colour in groundwater.

5.3.4 Turbidity

Turbidity or cloudiness is an optical property of water, which can be described by the observation that when a beam of light passes through muddy water the intensity of the light is reduced. This reduction caused by the suspended material in water, is a measure of water's turbidity.

5.3.5 Temperature

The temperature of groundwater largely depends on atmospheric temperature, terrestrial heat, exothermic and endothermic reactions in rocks, infiltration of surface water, insulation thermal conductivity of rocks, rate of movement of groundwater and interface of men on the groundwater regime. The depth of the source of a groundwater could be gauged from the temperature of the water.

5.3.6 Taste and Odour

The taste and odour of groundwater is mainly due to the presence of foreign matter such as organic compounds, inorganic salts or dissolved gases in groundwater. Odour estimation determines whether the water is of acceptable quality and also the presence of pollution. If the water contains hydrogen sulphide, it imparts the rotten-egg smell. Gases and some organic compounds and minerals may give unpleasant taste and odour to groundwater.

5.3.7 Density

The density is a significant physical property that affects the behaviour in the natural system and may influence its chemical composition in an indirect way. In many groundwater assessment studies, evaluation of the quality of groundwater is as important as the quantity. The usability of

groundwater available is determined by its chemical, physical and bacteriological properties.

5.4 DISSOLVED CONSTITUENTS IN GROUNDWATER

5.4.1 Silica

The crystalline form of silica, feldspars, feldspathoids, amphiboles, pyroxene and mica the silicate minerals are the chief source of silica in groundwater. In the freshwater, silica comes next in abundance to bicarbonate, but at higher concentrations the silica content is usually less than sodium bicarbonate, sulphate and chloride. Normal concentrations of silica are found in some highly alkaline waters, and also in some acidic waters. Relatively high concentrations observed in water from many hot springs reflect the increase in solubility with temperature (Hem, 1970).

5.4.2 Iron

Iron may be acquired in solution by groundwater from well casings, delivery pipes, etc. Most tube wells yield iron-rich water on pumping after prolonged idle periods. Usually, iron occurring in groundwater is in the form of ferric hydroxide, with less than 0.5 ppm concentration. Higher concentrations of iron are attained by water with low pH (acid waters), and by waters derived from swamps and peat bogs. However, a reduction in the iron content can be brought about by aeration of waters containing ferrous iron.

5.4.3 Manganese

Manganese accumulates can be observed in residual deposits such as laterite and soil. The common manganese bearing minerals are oxides, hydroxides, carbonates and silicates. Under reduced conditions, in most of the

groundwater, manganese content is less than 0.2 ppm but in low pH water higher manganese content may be attained.

5.4.4 Calcium

Carbonate rocks are the chief source of calcium in natural water and on global scale they contribute 80% or more of the calcium in streams. Silicate mineral groups like plagioclase, pyroxene and amphibole among igneous and metamorphic rocks and limestone, dolomite and gypsum among sedimentary rocks are the main source of calcium in groundwater. Silicate minerals are not soluble in water, but weathering breaks them down into soluble calcium products and clay minerals. The carbonates and sulphates of calcium however, are soluble in water. Due to its abundance in most of the rocks and its solubility, calcium is present almost everywhere in groundwater.

In the presence of water containing carbon dioxide in dissolved form calcium carbonate is quite soluble, the reaction being broadly as given in equation 5.1,

$$CaCO_3 + H_2O + CO_2 \leftrightarrow Ca(HCO_3)_2 \qquad (5.1)$$

Calcium carbonate continues to dissolve as long as there is carbonic acid in the water, but precipitation of calcium carbonate may occur once the acid is used up. The causes for the precipitation of calcium carbonate from groundwater are evaporation, increase in temperature, decrease in pressure and pH beyond 8.2.

5.4.5 Magnesium

In groundwater the magnesium is derived part from silicates and part from magnesium calcite or dolomite. Mica from intensive weathering of

mafic rocks and from pyroxene and amphiboles give rise to silicates. The weathering of igneous and metamorphic rocks gives rise to soluble carbonates, clay and silica. In the presence of carbonic acid in water magnesium carbonate is converted into more soluble, bicarbonate which is shown in equation 5.2

$$MgCO_3+CO_2+H_2O\leftrightarrow Mg(HCO_3)_2 \quad (5.2)$$

Under ordinary atmospheric condition the solubility of magnesium carbonate in water in the presence of carbon dioxide is nearly ten times that of calcium carbonate. In groundwater the calcium content generally exceeds the magnesium content in accordance with its relative abundance in rocks but contrary to the relative solubility's of its salts. In seawater, however, the ratio of calcium to magnesium is about 1 to 5. High magnesium content in groundwater in coastal area indicates seawater contamination.

5.4.6 Sodium

Most of the sodium salts are soluble in water, but take no active part in chemical reactions, as do the salts of alkaline earths. Sodium salts tend to remain in solution unless extracted during evaporation. In saline water, the sodium content may be several hundred times the total amount of the calcium and magnesium contents. Sodium bearing minerals like albite and other members of plagioclase feldspars, nepheline, sodalite, glaucophane, aegirine etc. are not as widespread or abundant as the calcium and magnesium bearing minerals. Weathering of these rocks gives rise to soluble sodium. The most important source of sodium in groundwater particularly in arid and semi-arid regions is the precipitation of this salt impregnating the soil in the shallow water tracts. Sodium content in ground water ranges from about 1 ppm in humid and snow-fed regions to over 10,000 ppm in brines. In general, when

the total dissolved solids increases the concentration of sodium and chloride increases. An increase in sodium with concomitant reduction of calcium and magnesium, preponderance of sodium over chloride ions, or alternation of calcium carbonate to sodium carbonate may be indicative of Base Exchange enrichment of sodium if such changes are not accomplished by an increase in the total mineralization of groundwater. Groundwater in well-drained areas with good amounts of rainfall usually has less than 10 to 15 ppm of sodium.

5.4.7 Potassium

Potassium is nearly as abundant as sodium in igneous rocks and metamorphic rocks but its concentration in groundwater is one-tenth or even one hundredth of sodium. The potassium is derived from silicate minerals like orthoclase, microcline, nepheline, leucite and biotite. Parity in concentrations of sodium and potassium is found only in water with less mineral contents. Two factors are responsible for the scarcity of potassium in groundwater one being the resistance of potassium minerals to decomposition by weathering and the other being the fixation of potassium in clay minerals formed due to weathering. The concentration of potassium ranges from 1ppm or less to about 10 to 15 ppm in potable waters, and from 100 ppm to over several thousand ppms in some brines. Potassium salts, being more soluble than sodium salts, are the last to crystallize during evaporation.

5.4.8 Carbonate and Bicarbonate

The dissolved carbon dioxide derived from rain is the primary source of carbonate and bicarbonate ions in groundwater. As it enters the soil, it dissolves more carbon dioxide in water. Carbon dioxide is also released from the organic matter during the decay. Water charged with carbon dioxide dissolves carbonate minerals, as it passes through soil and rocks, to give

bicarbonates. Carbonate dissolution from rocks and precipitation from water is a two-way process dependent on the partial pressure of carbon dioxide. Under usual conditions the bicarbonate concentration in groundwater ranges mainly from 100 to 800 ppm (Karanth 1987). The bicarbonate content is fairly constant because of only small variations in the partial pressure of carbon dioxide in the interstitial pores of the rocks in the aeration zone.

5.4.9 Sulphate

Groundwater present in igneous or metamorphic rocks contains less than 100 ppm sulphate (Davis and Dewiest 1966). The sulphate content of atmospheric precipitation is only about 2 ppm, but a wide range in sulphate content in groundwater is made possible through oxidation, precipitation, solution and concentration, as the water traverses through rocks. In sulphide mineralization zones, solution of other sulphide minerals like chalcopyrite, sphalerite, etc. can be induced by ferric sulphate (Bateman 1960). The reaction equations are given in 5.3 and 5.4

$$CuFeS_2 + 2Fe_2(SO_4) \rightarrow CuSO_4 + 5FeSO_4 + 2S \quad (5.3)$$

$$ZnS + 4Fe_2(SO_4)_3 + 4H_2O \rightarrow ZnSO_4 + 8FeSO_4 + 4H_2SO_4 \quad (5.4)$$

At ordinary temperature the sulphate of calcium can be dissolved in water up to a concentration of about 1500 ppm. Water contains chiefly magnesium and sodium, but little calcium may attain sulphate concentration exceeding 100,000 ppm and even up to 200,000 ppm in certain types of magnesium brines (Hem 1970). Reduction of sulphate by bacteria and precipitation of gypsum may cause removal of sulphate in groundwater. Reduction of sulphate by bacteria is the main cause of hydrogen sulphide gas emanating from groundwater in association with lignite and coal.

5.4.10 Chloride

The chloride content of ocean water, an important entity in the hydrological cycle, is of the order of 13,000 ppm, the chloride content of rainwater may be high in coastal areas and in desert tracts. Chloride bearing rock minerals such as Sodalite and Chlorapatite, which are very minor constituents of igneous and metamorphic rocks and liquid inclusions which comprise very insignificant fraction of the rock volume, are minor sources of chloride in groundwater. Chloride salts, being highly soluble and free from chemical reactions with minerals of reservoir rocks, remain stable once they enter in solution. Most chloride in groundwater is present in sodium chloride, but the chloride content may exceed the sodium due to base-exchange phenomena. Calcium and magnesium chloride waters are rather rare. Abnormal concentrations of chloride may result due to pollution by sewage wastes, common salt added to coconut plantation and leaching of saline residues in the soil.

5.5 CLASSIFICATION OF GROUNDWATER

The classification of groundwater can be done based on its quality and usage.

5.5.1 Total dissolved solids

World Health Organization (WHO, 1984) has reported that about 80% of the health hazards occur in world, due to the poor quality of water used for consumption. Water with high TDS indicates more ionic concentration, which is inferior and can cause physiological disorders to its user (Subba Rao et al 2002). TDS is one of the important factors that determine the suitability of water for various uses. Carroll (1962) proposed a classification of groundwater based on the TDS content shown in Table 5.4.

Table 5.4 Groundwater classification on the basis of TDS

Total Dissolved Solids (mg/l)	Category
Up to 1000	Fresh Water
1000 – 10,000	Brackish Water
10,000 – 100, 000	Saline Water
Above – 100,000	Brine Water

(Carroll, 1962)

5.5.2 Total Hardness

Total Hardness results from the presence of divalent metallic cations, of which calcium and magnesium are the most abundant in groundwater. The terms 'hard' and 'soft' as applied to water date from Hippocrates (460 – 354 BC) the father of medicine, in his treatise on public hygiene, air, water and places: "Consider the water which the inhabitants use, whether they be marshy and soft, or hard and running from elevated rocky situations, and then if saltish and unfit for cooking, for water contributes much to health."

The hardness in water is derived from solution of CO_2, released by bacterial action in the soil, in percolating rainwater. Hardness (H_T) is expressed as the equivalent of calcium carbonate.

Thus,

$$HT = Ca \times \frac{CaCO_3}{Ca} + Mg \times \frac{CaCO_3}{Mg} \qquad (5.5)$$

Where HT, Ca and Mg are measured in milligrams per liter, and the ratios in equivalent weights

Total Hardness denotes the concentration of calcium and magnesium in water and is usually expressed as the equivalents $CaCO_3$

Total Hardness (TH) = 2.497Ca + 4.11 Mg (5.6)

(Karanth, 1987)

Where, TH, Ca, Mg are all measured in ppm.

The classification of groundwater is made by Sawyer and Mccarty (1987) using the total hardness present in groundwater, which is given in the Table 5.5.

Table 5.5 Classification of Water based on Hardness

S.No.	Hardness mg/l as $CaCO_3$	Water Class
1.	0 – 75	Soft
2.	75 – 150	Moderately Hard
3.	150 – 300	Hard
4.	Over 300	Very Hard

(Sawyer and McCarty, 1987)

5.5.3 Hardness

The presence of Calcium and Magnesium along with Carbonate / Bi-carbonate, Sulphate and Chloride causes the hardness in ground water. These ions react with soap to form precipitation and with certain anions present in the water to form scales. The Hardness in water is derived from the solution of carbon-dioxide released by bacterial action in the soil, in percolating rainwater (Todd 1980). There are two types of hardness in

groundwater namely, ‘temporary’ and ‘permanent’. The temporary hardness is due to the presence of Carbonates of Calcium or Magnesium and Calcium Sulphate or Chloride makes the water permanently hard.

5.5.4 Corrosivity Ratio

Corrosion is basically an electrolytic process, which severely attacks and corrodes away the metal surfaces. The rate at which corrosion proceeds depends upon a variety of chemical equilibrium reactions as well as upon certain physical factors like the temperature, pressure and velocity of flow (Ayers and Westcot 1985).

Ryzner (1944) proposed a ratio to assess the corrosive nature of the ground water on metals. Lawrence (1995) and Sridhar (2001) used this methodology to identify the corrosive ground water in Ramanathapuram District and Kodavanar basin respectively. The Corrosivity Ratio is calculated using the formula mentioned below:

$$\text{Corrosivity Ratio (CR)} = \frac{\frac{Cl(mg/1)}{35.5} + \frac{2SO_4(mg/1)}{69}}{2\left(\frac{CO_3 + HCO_3(mg/1)}{100}\right)} \qquad (5.7)$$

If the CR is < 1, then the water is non-corrosive and if the CR > 1, then the water is corrosive (Rengarajan et al 1990).

5.5.5 Schoeller Water Type

Schoeller (1965a) has described that the first and foremost waters are those in which:

$rCO_3 > rSO_4$……Type - I

as the total concentration increases the above relation to

$rSO_4 > rCl$……..Type - II

still at higher concentration, the water may change to

$rCl > rSO_4 > rCO_3$……Type – III

and at the final stages

$rCl > rSO_4 > rCO_3$ and $rNa > rMg > rCa$……..Type – IV

5.5.6 Stuyfzand Classification

Stuyfzand (1989) has proposed a method of classification of groundwater and identified 8 main types on the basis of CL shown in Table 5.6. It is used for identification of freshwater flow zone from the zone of salt-water intrusion.

Table 5.6 Stuyfzand Classifications

Main Type	Cl (mg/l)	Main Type	Cl (mg/l)
Very Oligohaline	< 5	Brackish	$300 - 10^3$
Oligohaline	5 – 30	Brackish – Salt	$10^3 – 10^4$
Fresh	30 – 150	Salt	$10^4 – 2 X 10^4$
Fresh-Brackish	150 – 300	Hyperhaline	$> 2 X 10^4$

(Stuyfzand,1989)

Using this methodology, Balsubramanian et al (1991), Subramanian (1994) and Lawrence (1995) classified ground water of Tuticorin, Thiruchendur and Ramanathapuram coast, respectively.

5.5.7 USSL Classification

United States Salinity Laboratory (USSL) has proposed a classification for rating of irrigation water with reference to salinity and

Sodium Hazard (Richards 1954). The total dissolved solids content is measured in terms of specific electrical conductance (Ec µmhols/cm) and gives the salinity hazard of irrigation water. Besides the salinity hazard, excessive sodium in water renders it unsuitable for soils, containing exchangeable Ca^{++} and Mg^{++} ions. If the percentage of Na^{++} to $Ca^{++}Mg^{++}$ + Na^{++} is considerably above 50 ppm in irrigation waters, soils containing exchangeable Calcium and Magnesium take up sodium in exchange for Calcium and Magnesium causing deformation and harm the tilth the permeability of soils. The sodium hazard in irrigation water is expressed by determining the Sodium Adsorption Ratio (SAR) by the relation in which concentrations are expressed in milliequivalents per litre (meq/l).

$$SAR = \frac{Na}{\sqrt{\frac{(Ca + Mg)}{2}}} \tag{5.8}$$

With reference to salinity and SAR, the irrigation water quality with low salinity and low SAR has been classified as C_1S_1 and with higher as C_4S_4.

5.5.8 Mechanism Controlling Water Chemistry

The mechanism that controls water chemistry has been discussed by Conway (1942), Gorham (1961), Mackenzie and Garrels (1965, 1966), Gibbs (1970) and Ramesem and Barua (1973). Among all these methods, Gibbs method is widely used. Sastri (1974) established the relationship of water composition to aquifer lithology. Such relationship would explain not only the origin and distribution of the dissolved constituents but also elucidate the factors controlling groundwater chemistry. Adopting this method, Subramanian (1994) and Ramanathan et al (2001) identified the mechanism controlling water chemistry under various environments.

5.5.9 Digital Data Processing

Balasubramanian et al (1991b) developed a computer program in BASIC language, called HYCH (Hydrochemistry) (Appendix- A), which can classify the ground water. The program has been written covering the following aspects in it, which are shown in Tables 5.7, 5.8, 5.9 and 5.10.

Table 5.7 Sources of Basic Criteria used in HYCH

Parametric study	Source
$CaCO_3$ Saturation Indices	Bhandari et al (1975), Back (1961, 63), Hem (1961), Larson et al (1942), Robertson (1964).
Handa's Classification	Handa (1964)
Piper's Classification	Piper (1944)
Mechanisms Controlling Groundwater Chemistry	Gibbs (1970)
Indices of Base – Exchange & Water Types	Schoeller (1965)
Stuyfzand's Classification	Stuyfzand (1989)
Percentage Permissible Error	Richards (1954)
Corrosivity Ratio	Ryzner (1944), Badrinath et al (1964)
Sodium Absorption Ratio	Raghunath (1987)
Residual Sodium Carbonate	
Non-Carbonate Hardness	

Table 5.8 Basic criteria used in Handa's classification

	Ca^{++}	Mg^{++}	$Ca^{++}Mg^{++}$	$Cl^{--}SO_4$	Characteristics
A1	>	HCO_3^-	> Na + K	< HCO_3^-	Non-Carbonate Hardness
A2	>	HCO_3^-	> Na + K	> HCO_3^-	Non-Carbonate Hardness
A3	>	HCO_3^-	< Na + K	> HCO_3^-	Non-Carbonate Hardness
B1	<	HCO_3^-	> Na + K	< HCO_3^-	Carbonate Hardness
B2	<	HCO_3^-	< Na + K	< HCO_3^-	Carbonate Hardness
B3	<	HCO_3^-	< Na + K	> HCO_3^-	Carbonate Hardness
Salinity			TSC or TSA (epm)		
C1	Low		<2.5		
C2	Low – Medium		2.5 – 7.5		
C3	Medium – High		7.5 – 22.5		
C4	High – Very High		22.5 – 37.5		
C5	Extremely High		> 37.5		
Type			Sodium Hazard (%)		
S1	Low Sodium water		0.0 – 30.0		
S2	Low – Medium Sodium Water		30.0 – 57.5		
S3	Medium – High Sodium Water		57.5 – 100.0		

(Handa, 1964)

Table 5.9 Classification of Hydro-chemical Facies

Facies	Percentage of Constituents			
	Ca + Mg	**Na + K**	**$HCO_3 + CO_3$**	**$Cl + SO_4$**
Cation Facies				
Calcium – Magnesium	90 – 100	0 < 10	--	--
Calcium – Sodium	50 – 90	10 < 50	--	--
Sodium – Calcium	10 – 90	50 < 90	--	--
Sodium – Potassium	0 – 10	90 – 100	--	--
Anion Facies				
Bicorbonate	--	--		
Bicorbonate – Chloride	--	--	90 – 100	0 < 10
Chloride – Sulphate	--	--	50 – 90	10 < 50
Bicorbonate	--	--	10 – 50	0 < 50
Chloride – Sulphate	--	--	0 – 10	90 – 100

(After Back, 1963)

Table 5.10 Stuyfzand's water types based on saturation index

Saturation Index	Water Characteristics
= 0	In equilibrium with $CaCO_3$
> 0	Over-saturated with $CaCO_3$
< 0	Under-saturated with $CaCO_3$

(Stuyfzand, 1989)

The quality assessment can be done at a faster rate without resorting to tedious graphical procedures by employing this program and the following information can be obtained from the analyzed results of ground water.

- Total Dissolved Solids
- Handa's Classification
- Corrosivity ratio
- Schoeller's water type
- Stufyzand water type and significant environment
- USSL Classification
- Groundwater Hardness

Other information's provided by the program are:

- Sodium Absorption Ratio
- Residual Sodium Carbonate
- Indices of Base Exchange
- $CaCO_3$ Saturation Indices
- Gibb's Plot
- Piper's Geochemical Facies

The sample output of the computer program is given in Figure 5.2 and the result based on HYCH program for both the seasons is illustrated in Tables 5.11 and 5.12.

Table 5.11 HYCH Output Results of the Study area Pre Monsoon

Sl.No	Sample Location	Water Classification	USSL Classification	Corrosivity Ratio	Gibbs	Cl / HCO_3 +CO_3	Total Hardness	SAR
1	Alangulam	Fresh-brackish	C4S2	4.1586	ROCK INTERACTION	2.3246	311.9	5.4007
2	Ananda_puram	Fresh-brackish	C4S2	0.7202	EVAPORATION	0.3766	387.4	6.8911
3	Anandapuram	Fresh-brackish	C3S2	0.7439	ROCK INTERACTION	0.4440	259.33	5.2062
4	Bagavathipuram	Brackish	C3S2	1.0725	ROCK INTERACTION	0.6066	418.9	6.2638
5	Ittamozhi	Fresh	C2S1	0.3929	ROCK INTERACTION	5.5556	118.5	1.3980
6	Ittamozhipudur	Fresh-brackish	C3S1	0.7400	ROCK INTERACTION	0.4145	334.65	4.1596
7	Karunkadal	Fresh-brackish	C3S2	1.1498	ROCK INTERACTION	0.6333	298.3	4.7854
8	Karunkulam	g-Oligohaline (Saline)	C2S1	0.0998	ROCK INTERACTION	0.0561	178.1	0.9774
9	Kausturirangapuram	Fresh-brackish	C3S1	1.5369	ROCK INTERACTION	0.9189	295.1	3.1655
10	Kausturirangapuram (a)	Brackish	C4S1	2.1440	ROCK INTERACTION	1.2596	388.6	2.4918
11	Kavalkinar	Fresh-brackish	C4S2	1.0204	ROCK INTERACTION	0.5678	328.1	7.0240
12	Mannarpuram_vilakku	Fresh	C3S1	0.9190	ROCK INTERACTION	0.4197	196.2	4.8451
13	Moolaikaraipatti	Fresh	C2S1	0.5926	ROCK INTERACTION	0.2333	149.2	0.9967
14	Munanjipatti	Brackish	C4S2	3.6208	ROCK INTERACTION	2.0417	333.91	6.9858
15	Nanguneri	Fresh-brackish	C3S2	1.9185	ROCK INTERACTION	1.2856	192.7	6.9825
16	Padukkapathu	Brackish	C3S2	1.8658	ROCK INTERACTION	1.0777	332.1	6.3882

Table 5.11 (Continued)

17	Panagudi	Fresh-brackish	C3S1	0.9080	ROCK INTERACTION	0.4874	358.4	3.2871
18	Parappadi	Fresh-brackish	C3S2	2.3382	ROCK INTERACTION	1.3356	170.2	7.5950
19	Pudukulam	g-Oligohaline	C1S1	1.1584	PRECIPITATION	0.7258	39.1	0.7654
20	Radhapuram	Fresh	C2S1	0.7122	ROCK INTERACTION	0.4216	138.3	2.4769
21	Samugarengapuram	Brackish	C3S2	1.7863	ROCK INTERACTION	1.1624	448.89	4.6339
22	Soundaralingapuram	Brackish	C4S3	4.0350	ROCK INTERACTION	2.1551	334.35	10.0999
23	Sundarapuram	Fresh-brackish	C3S1	1.6153	ROCK INTERACTION	1.0155	274.62	3.6732
24	Tiruchendur	Fresh	C2S1	0.5927	ROCK INTERACTION	0.3565	205	1.6088
25	Tirukkurungudi	Fresh	C3S4	0.6240	ROCK INTERACTION	0.2675	50.01	18.3296
26	Tulukkarpatti	Fresh-brackish	C3S1	2.0253	ROCK INTERACTION	1.2711	269.57	4.0767
27	Udankudi	g-Oligohaline	C2S1	0.4977	ROCK INTERACTION	0.2001	56.2	3.3624
28	Unnankulam	Fresh	C3S1	1.0654	ROCK INTERACTION	0.6109	299.2	1.9598
29	Uvari	Brackish-salt	C5S4	4.6860	EVAPORATION	2.9057	397.1	12.2872
30	Vadakku Vijayanarayanam	Fresh-brackish	C4S3	1.3389	EVAPORATION	0.4682	199.65	13.5624
31	Valliyoor	Fresh	C3S1	1.1301	ROCK INTERACTION	0.5031	226.5	4.4212
32	Vijayapathi	Brackish	C4S3	7.7349	ROCK INTERACTION	2.9053	329.6	11.7366

Table 5.12 HYCH Output Results of the Study area Post Monsoon

Sl.No.	Sample Location	Water Classification	USSL Classification	Corrosivity Ratio	Gibbs	Cl / HCO_3 +CO_3	Total Hardness	SAR
1	Alangulam	Fresh-brackish	C3S1	1.9296	ROCK INTERACTION	1.1612	249.3	4.5434
2	Ananda_puram	g-Oligohaline	C1S1	0.8301	ROCK INTERACTION	0.5	35.7	1.4559
3	Anandapuram	Brackish-salt	C5S4	13.9212	EVAPORATION	8.3044	108.5	12.986
4	Bagavathipuram	Fresh-brackish	C3S2	1.6009	ROCK INTERACTION	0.9836	227.5	5.245
5	Ittamozhi	Brackish	C3S1	1.8967	ROCK INTERACTION	1.2456	445.6	2.4097
6	Ittamozhipudur	Fresh	C2S1	0.3304	ROCK INTERACTION	0.1562	129.2	2.3332
7	Karunkadal	Brackish	C3S2	1.2343	ROCK INTERACTION	0.7252	479.28	5.5596
8	Karunkulam	Brackish	C4S3	2.88	ROCK INTERACTION	1.6035	403.2	9.2999
9	Kausturirangapuram	Fresh-brackish	C4S1	9.8309	ROCK INTERACTION	2.3862	103.2	1.1095
10	Kausturirangapuram (a)	Brackish-salt	C5S4	3.9045	EVAPORATION	2.2062	436.1	14.707
11	Kavalkinar	g-Oligohaline	C1S1	0.4334	PRECIPITATION	0.2337	53.9	0.4146
12	Mannarpuram_vilakku	Fresh	C3S1	0.6244	ROCK INTERACTION	0.3814	151.7	2.7537
13	Moolaikaraipatti	Fresh	C3S1	1.0051	ROCK INTERACTION	0.5489	182.8	2.1556
14	Munanjipatti	g-Oligohaline	C1S1	1.0538	PRECIPITATION	0.6	32.3	0.765

Table 5.12 (Continued)

15	Nanguneri	Fresh-brackish	C3S1	1.3846	ROCK INTERACTION	0.878	252.7	4.4309
16	Padukkapathu	Brackish-salt	C5S2	6.7079	ROCK INTERACTION	3.7774	105.9	6.3905
17	Panagudi	Fresh	C2S1	0.4014	ROCK INTERACTION	0.2723	113.6	3.2191
18	Parappadi	Fresh-brackish	C3S1	1.4933	ROCK INTERACTION	0.9321	345	1.6623
19	Pudukulam	Brackish	C4S4	0.6717	EVAPORATION	0.4252	239.77	14.157
20	Radhapuram	Fresh	C3S1	1.0846	ROCK INTERACTION	0.5943	359.4	1.2154
21	Samugarengapuram	Fresh	C2S1	0.572	ROCK INTERACTION	0.368	106	2.0691
22	Soundaralingapuram	g-Oligohaline	C2S1	0.5361	ROCK INTERACTION	0.295	92.8	0.7222
23	Sundarapuram	Brackish	C4S2	5.4621	ROCK INTERACTION	3.6598	288.08	3.7329
24	Tiruchendur	Brackish-salt	C4S2	8.1506	ROCK INTERACTION	5.1936	165.1	4.9837
25	Tirukkurungudi	Brackish-salt	C5S2	25.5384	ROCK INTERACTION	16.273	152.6	5.0076
26	Tulukkarpatti	Fresh	C2S1	0.764	ROCK INTERACTION	0.4793	126.3	1.8172
27	Udankudi	Brackish	C4S2	4.6634	ROCK INTERACTION	2.7819	299.35	5.9535
28	Unnankulam	Brackish	C4S2	3.3579	ROCK INTERACTION	2.0831	259.26	6.9269
29	Uvari	Fresh-brackish	C3S1	2.7861	ROCK INTERACTION	1.5902	321.3	4.0487
30	Vadakku Vijayanarayanam	Brackish	C4S2	14.6225	ROCK INTERACTION	9.7596	318.59	3.6576
31	Valliyoor	Brackish-salt	C5S2	13.0326	ROCK INTERACTION	7.6721	111.9	6.2146
32	Vijayapathi	Fresh	C3S1	1.1123	ROCK INTERACTION	0.6292	155.4	4.6718

TDS= 2213
PERMISSIBLE ERROR FOR THIS TDS IS = 1.787
TSC= 36.47243 TSA= 31.74397
OBSERVED ERROR= 6.931561
ERROR IN ANALYSIS
OBSERVED CATIONS
216 97.2 407
CORRECTED CATIONS UNIFORMLY UPGRADED TO BALANCE THE ANIONS AS
187 84 354

SAMPLE CODE = **ALANGULAM**

EC(mmhos) = 3600 TDS (ppm) = 2213
pH = 7.8 ORP = 0
DDO = 0 Temp.(centig) = 25

Conc/Ion	Ca	Mg	Na+K	HCO3	CO3	Cl	NO3	SO4
ppm	187.0	84.0	354.0	305.0	0.0	709.0	84.0	259.0
epm	9.3	6.9	15.4	5.0	0.0	20.0	1.4	5.4
%	29.5	21.8	48.7	15.7	0.0	63.0	4.3	17.0

Sodium Adsorption Ratio = 5.40071
Residual Sodium Carbonate=-11.24512
Non-carbonate Hardness = 562.2562
Permeability Index(Doneen)= 55.72032
IONIC STRENGTH = 0.0425 CORROSIVITY RATIO = 4.1586
INDICES OF BASE EXCHANGE = 0.2304 0.3922
CaCO3 SATURATION INDICES :
Equilibrium Ca method= 0.0640 Equilibrium pH method= 1.2686
GIBB'S PLOT : MECHANISM CONTROLLING THE CHEMISTRY = ROCK INTERACTION

HANDA'S CLASSIFICATION :
Hardness =A2 Permanent
Salinity =C5 V.High
Sodium hazard =S3 High

SCHOELLER'S WATER TYPE (r=epm)
III Since rCL > rSO4 > rCO3

PIPER'S HYDROGEOCHEMICAL FACIES:
Cations = Ca+Mg, Na+K Anions = Cl+SO4, HCO3+CO3
SIGNIFICANT ENVIRONMENT : WATERS CONTAMINATED WITH GYPSUM

STUYFZAND'S CLASSIFICATION:
WATER TYPE(Based on Cl) =B-Brackish
SUB-TYPE(Based on Alk) =ALK-MOD-HIGH
FACIES =Ca Cl
SIGNIFICANT ENVIRONMENT :
(.) Na&Mg EQBM INDICATE ADEQUATE FLUSHING WITH WATER OF CONST.COMP

USSL CLASSIFICATION:
Salinity =C4 Sodium hazard = S2

Figure 5.2 Computer Output of HYCH Program

5.6 GROUNDWATER QUALITY ASSESSMENT

The groundwater of Nambiyar river basin has been classified using various geochemical parameters in the following manner.

5.6.1 Total dissolved solids

In the study area TDS value ranges from 113 mg/l to 3493 mg/l in pre-monsoon period and 69.7 mg/l to 4139 mg/l in post-monsoon period. In pre monsoon the minimum TDS value was present in Pudukulam and maximum TDS value was present in Uvari. In post-monsoon season the minimum TDS value was present in Munanjipatti and the maximum value of TDS was present in Anandapuram. In Anandapuram, Ittamozhi, Ittamozhipudur, Karunkadal, Karunkulam, Kasturirangapuram, Mannarpuram vilakku, Moolaikaraipatti, Parappadi, Pudukulam, Radhapuram, Sundarapuram, Tiruchendur, Tirukkurungudi, Tulukkarpatti, Udankudi, Unnankulam and Valliyoor had potable TDS values less than 1000 mg/l in pre-monsoon season as shown in Figure. 5.3. In post-monsoon season Anandapuram, Bagavathipuram, Ittamozhi, Ittamozhipudur, Kavalkinar, Mannarpuram vilakku, Moolaikaraipatti, Munanjipatti, Nanguneri, Panagudi, Parappadi, Radhapuram, Samugarengapuram, Soundaralingapuram, Tulukkarpatti, Uvari and Vijayapathi had TDS values below 1000 mg/l shown in Figure 5.4 which is potable. In both pre and post-monsoon periods the following places viz. Ittamozhi, Ittamozhipudur, Mannarpuram vilakku, Moolaikaraipatti, Parappadi, Radhapuram, Tulukkarpatti are found suitable as potable sources.

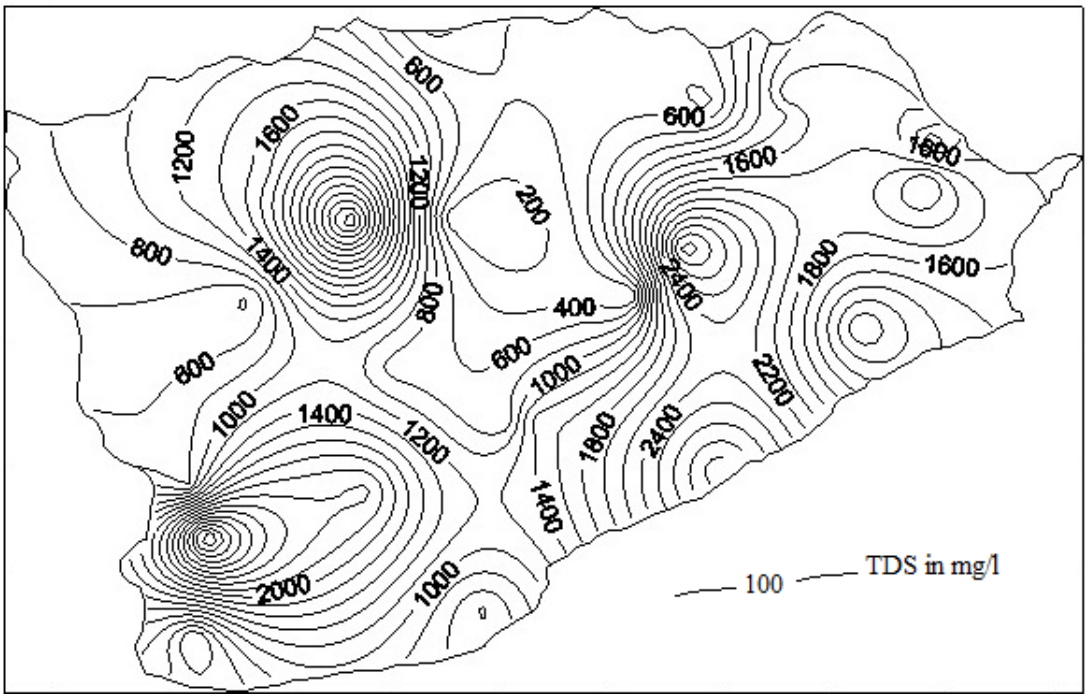


Figure 5.3 Spatial Variation of Total Dissolved Solids during January 2009

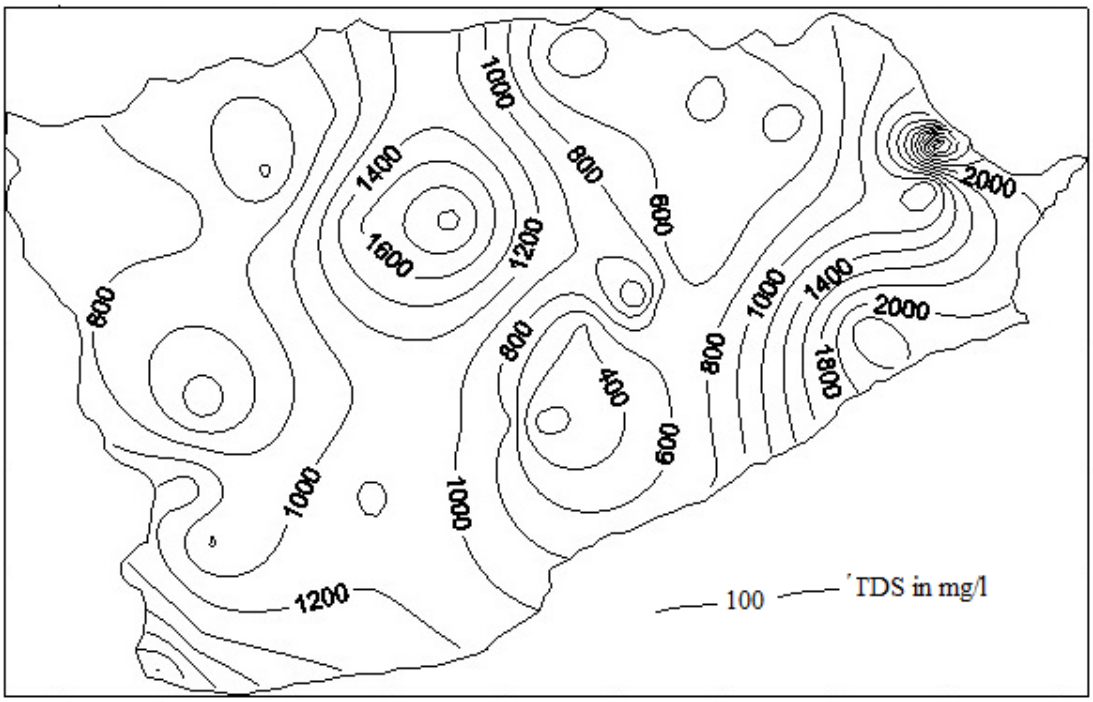


Figure 5.4 Spatial Variation of Total Dissolved Solids during July 2009

5.6.2 Hardness

The total hardness has been calculated in the study area for the 32 sample locations. The water which has total hardness values less than 75 mg/l are considered as soft water. In the present study area three different places have been identified as the soft water sources. In pre-monsoon season Pudukulam, Tirukkurungudi and Udankudi were identified as the soft water sources.

In post-monsoon period Munanjipatti, Anandapuram and Kavalkinar were identified as the soft water sources. Moderately hard water occurs in a few locations like, Ittamozhi, Radhapuram and Moolaikaraipatti in pre-monsoon season and Soundaralingapuram, Samugarengapuram and Panagudi. Moderately hard water (75 mg/l – 150 mg/l) occurs in few locations like, Ittamozhi, Radhapuram and Moolaikaraipatti in pre-monsoon season and Soundaralingapuram, Samugarengapuram, Panagudi, Tulukkarpatti and Ittamozhipudur in post-monsoon season. Hard and very hard water occupy most of the location in the study area in both seasons. Uvari has the maximum total hardness of about 897.1 mg/l during pre-monsoon period whereas Tiruchendur has maximum hardness of about 1651 mg/l during post-monsoon period shown in Figures 5.5 and 5.6.

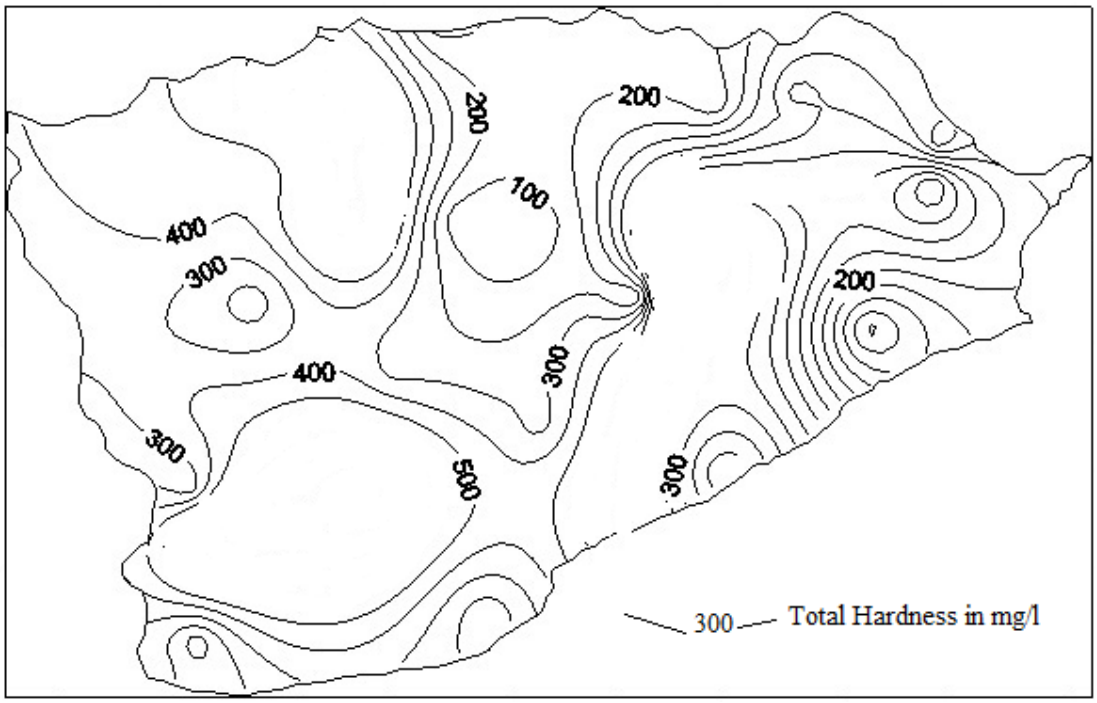


Figure 5.5 Spatial Variation of Total Hardness during January 2009

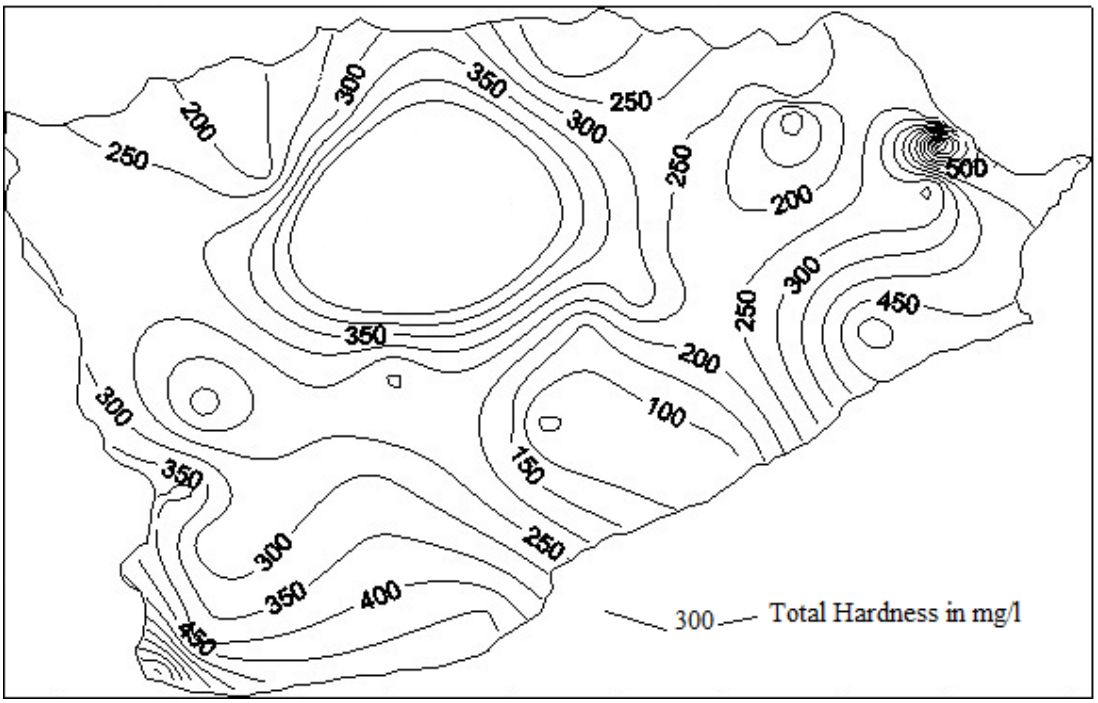


Figure 5.6 Spatial Variation of Total Hardness during July 2009

5.6.3 Corrosivity Ratio

According to Rengarajan et al (1990) the groundwater with corrosivity ratio more than 1 are considered to be corrosive water and it cannot be transported through metal pipes. It can only be transported through PVC pipes. The corrosivity ratio in the study area lies between 0.9998mg/l to 7.7349 mg/l in pre-monsoon and 0.3304mg/l to 25.5384 mg/l in post-monsoon season. In some locations like Karunkulam, Radhapuram,Panagudi, Valliyoor, Anandapuram, Bagavathipuram, Kavalkinar, Tirukkurungudi, Oolaikaraipatti, Udankudi, Kasturirangapuram and Tiruchendur the corrosivity ratio is less than 1in the pre-monsoon season. In the following locations viz. Panagudi, Parappadi, Moolaikaraipatti, Karunkadal, Ittamozhi, Bagavathipuram, Karunkulam, Sundarapuram and Anandapuram in post-monsoon season the corrosivity ratio is less than 1. Corrosive water exists in most of the location in the study area as shown in Figures 5.7 and 5.8.

During post-monsoon season, the groundwater gets diluted and this leads to lesser concentration of CO_3 and HCO_3. Due to the dilution of these anions, it is noticed that there is an increase in corrosivity ratio in post-monsoon period.

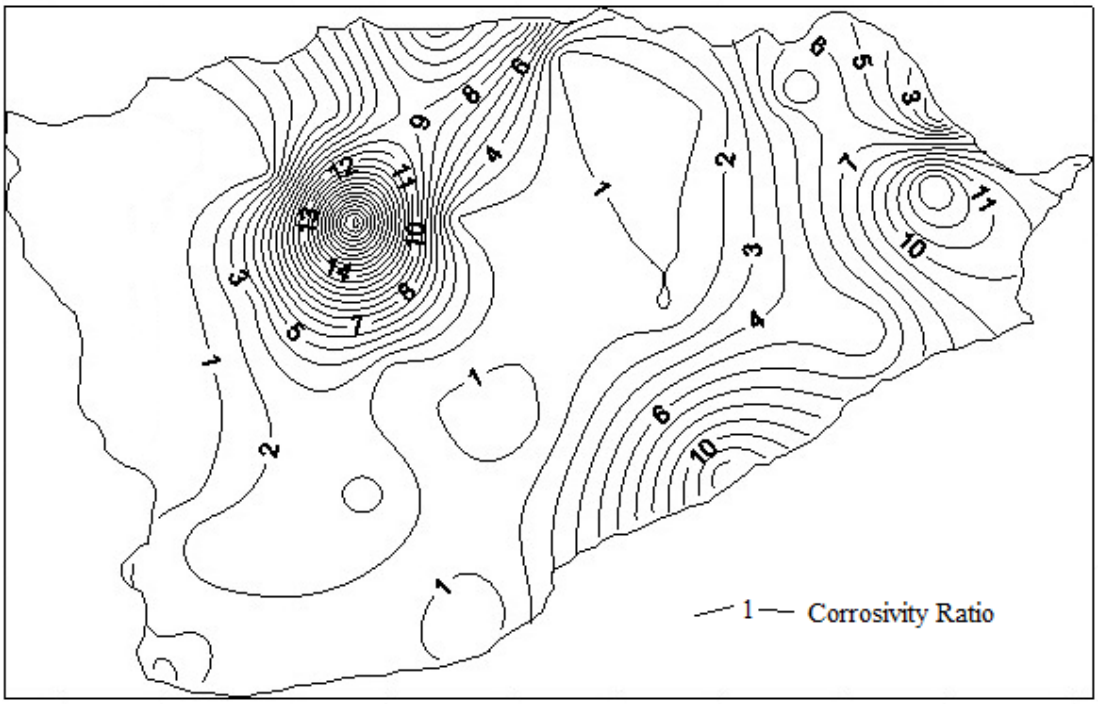


Figure 5.7 Spatial Variation of Corrosivity Ratio during January 2009

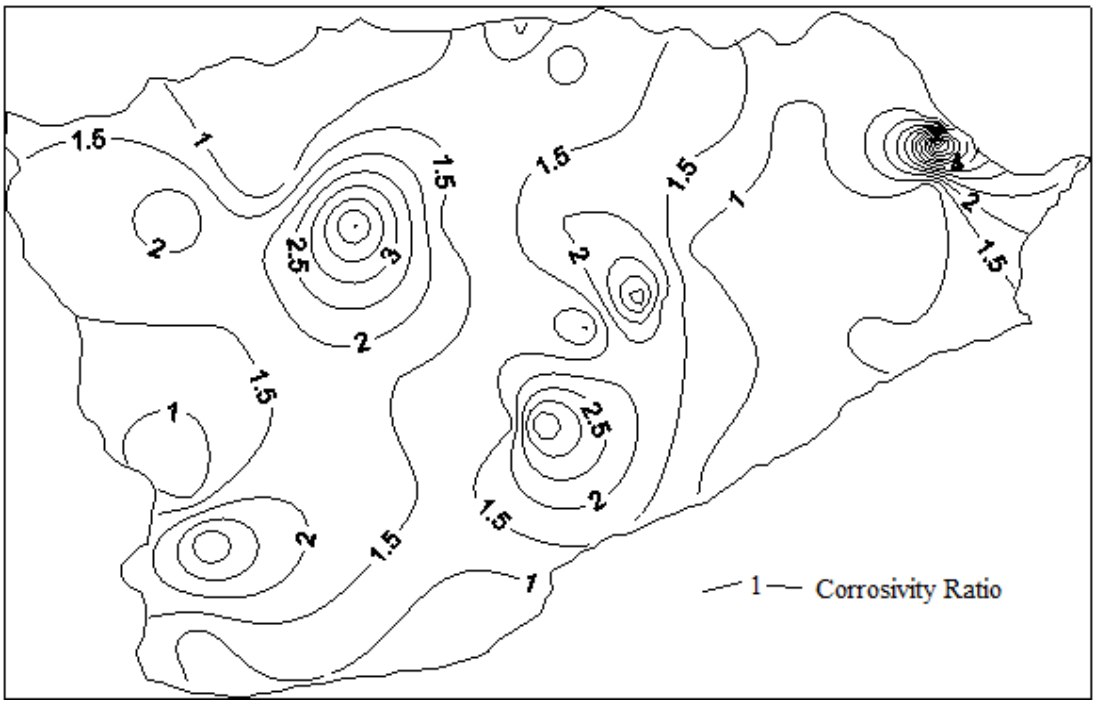


Figure 5.8 Spatial Variation of Corrosivity Ratio during July 2009

5.6.4 Stuyfzand Classification

Ground water classification maps using Stuyfzand classification is made from the HYCH. The study area is mainly occupied by fresh-brackish water during pre-monsoon seasons. During post-monsoon season the study area was mainly occupied by Brackish and fresh water. Mannarpuram vilakku, Moolaikaraipatti and Radhapuram were occupied by fresh water during pre-monsoon and post-monsoon seasons in the study area. During pre-monsoon period Karunkulam, Pudukulam and Udankudi were occupied by saline water and during post-monsoon period Anandapuram, Kavalkinar, Munanjipatti and Soundaralingapuram were occupied by saline water. Uvari was occupied by brackish-salt water during pre-monsoon season. In post-monsoon season Kausturirangapuram, Padukkapathu, Tiruchendur, Tirukkurungudi and Valliyoor were occupied by brackish-salt water.

5.6.5 USSL Classification

From the HYCH program output, USSL classification maps have been prepared for both the seasons as shown in Figure 5.9. C_1S_1, C_2S_1, C_3S_1, C_3S_2, C_3S_4, C_4S_1, C_4S_2, C_4S_3, and C_5S_4 water were present during pre-monsoon period in the study area. C_1S_1 water was present in Pudukulam. C_2S_1 water occupies Ittamozhi, Karunkulam, Moolaikaraipatti, Radhapuram, Tiruchendur, and Udankudi. C_3S_1 water covers Ittamozhipudur, Kausturirangapuram, Mannarpuram vilakku, Panagudi, Sundarapuram, Tulukkarpatti, Unnankulam, and Valliyoor. C_3S_2 water type covers Anandapuram, Bagavathipuram, Karunkadal, Nanguneri, Padukkapathu, Parappadi, and Samugarengapuram. C_3S_4 water type occurs in Tirukkurungudi. C_4S_1 water type was present in Kausturirangapuram area. C_4S_2 water type occurs in the following locations: Alangulam, Anandapuram, Kavalkinar, and Munanjipatti. C_4S_3 water occupied Soundaralingapuram,

Vadakku Vijayanarayanam, and Vijayapathi. C_5S_4 type water occupied Uvari. C_1S_1, C_2S_1, C_3S_1, C_3S_2, C_4S_1, C_4S_2, C_4S_3, C_4S_4, C_5S_2, and C_5S_4 water was present during post-monsoon season in the study area. Anandapuram, Kavalkinar, and Munanjipatti have C_1S_1 water. Ittamozhipudur, Panagudi, Samugarengapuram, Soundaralingapuram, and Tulukkarpatti area are covered by C_2S_1. C_3S_1 water occupies Alangulam, Ittamozhi, Mannarpuram vilakku, Moolaikaraipatti, Nanguneri, Parappadi, Radhapuram, Uvari and Vijayapathi. Bagavathipuram and Karunkadal are occupied by C_3S_2 type water. Kausturirangapuram areas have C_4S_1 type water. Sundarapuram, Tiruchendur, Udankudi, Unnankulam, and Vadakku Vijayanarayanam are occupied by C_4S_2 type water. Karunkulam area is occupied by C_4S_3 type water. Pudukulam area is covered by C_4S_4. Padukkapathu, Tirukkurungudi, and Valliyoor are occupied by C_5S_2 type water. Anandapuram area is occupied by C_5S_4 type water.

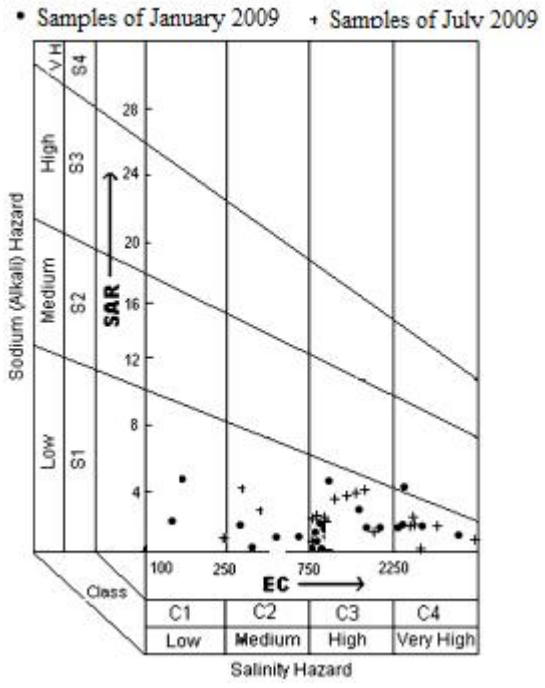


Figure 5.9 USSL Classification of Groundwater

5.6.6 GIBB'S Plot

From the output of HYCH, the mechanism controlling water chemistry for the present study area has been evaluated. In both pre and post-monsoon season's rock water interaction is dominant then evaporation and precipitation in the study area as shown in Figure 5.10. In Anandapuram, Uvari, and Vadakku Vijayanarayanam evaporation is seems to occur during pre-monsoon period. Precipitation occurs in Pudukulam during pre-monsoon season.

Evaporation seems to occur in areas like Anandapuram, Kausturirangapuram and Pudukulam in post-monsoon season. Kavalkinar and Munanjipatti have precipitation dominance during post-monsoon period.

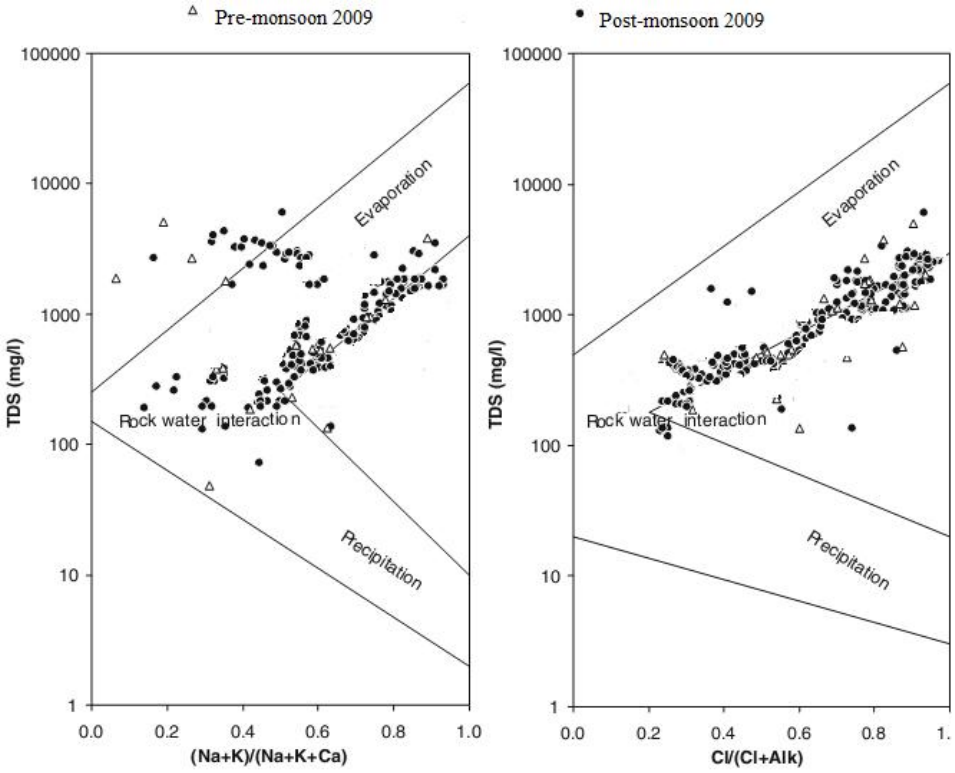


Figure 5.10 GIBB'S Plot of Groundwater

5.6.7 PIPER'S TRI-LINEAR DIAGRAM

Piper tri-linear diagram has been prepared and shown in figure 5.11. From the Piper's plotting, it is established that during pre-monsoon period strong acids exceeds weak acids and in few samples, weak acids exceeds the strong acids. But in post monsoon period, Mg content increases dramatically due to dissolution of Mg and marked decrease of Na+K is observed. This may be due to weathering pattern of basic and ultra basic rocks of that region and residence time of ground water. From anion point of few, CO_3 and HCO_3 exceed other anions, which indicate the water of this region is inordinately soft in proportion to their content of dissolved solids. During post monsoon period, the change in ionic strength may be to adequate recharge of groundwater.

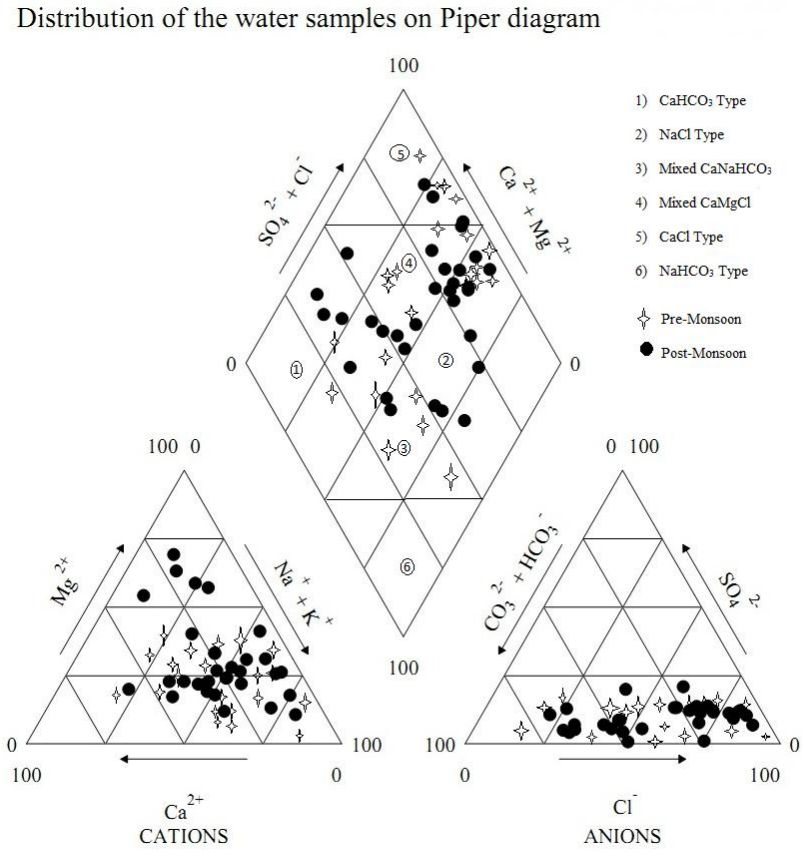


Figure 5.11 Distribution of the water samples on Piper's diagram

CHAPTER 6

STATISTICAL STUDIES

6.1 SURFACE WATER QUALITY TREND STUDY

6.1.1 General

Proper management of water resources is very important to meet the increasing demand of water in the future. The quality of water is characterized by various physico-chemical parameters. These parameters change widely due to many factors like source of water, type of pollution, seasonal fluctuations, etc. Statistical analysis viz., descriptive statistics, correlation and regression analysis of the physico-chemical properties of a river basin give a fairly good amount of information like their average values and possibly prediction of one variable (usually the one which is difficult to evaluate). Such studies have been carried out by many scholars in the past. Water quality monitoring is the cornerstone of water shed management, yet the desire to collect additional information is often frustrated by the lack of resources to support the sampling effort (xiaoqing and Todd 2005). Regression models are useful especially when only limited data are available in developing countries like India. Mass balance studies using water quality and flow data are extensively used during recent years to study the in-stream reactions and pollution loading patterns (Plummer and Back, 1980, Yuretich and Batchelder 1988, Jain 1996). Regression models are relatively cheaper and less time consuming (Chandrasekhar and Satyaprasad 2005).

In the present investigation an attempt has made to assess the trend of the surface water quality of Nambiyar River basin using statistical methods. The surface water quality data of Nambiyar River basin from the TNPWD has been used for the study for the years 2002, 2003 and 2004. Since the river is not perennial, the available data of the selected locations like Kodumudiyar Reservoir, Thirukurungudi, Eruvadi, Valliyur, Pulimangulam and Athankarai Pallivasal of the basin were taken for the analysis shown in Figure 6.1. The correlation coefficients among all the surface water quality characteristics were calculated. Linear regression equations were developed for the pairs of parameters, which have a significant influence on each other ($r > 8$ with significant 0.01; two tailed and $N = 8$).

The correlation analysis on surface water quality parameters reveals that all parameters are more or less correlated with each other. The correlation coefficient (r) of >8 was taken in to account to find the regression equations. The SPSS and Windows Excel were used as the statistical analysis tool. The term correlation (or co-variation) indicates the relationship between two variables such that the changes in the values of one variable cause the value of the other variable to change. We can establish inter-relationship between variables by statistical methods with a few sets of observations. It gives a rough but fairly useful indication of the water quality and also facilitates a rapid monitoring of the status of water pollution (Jeyaraj et al 2001).

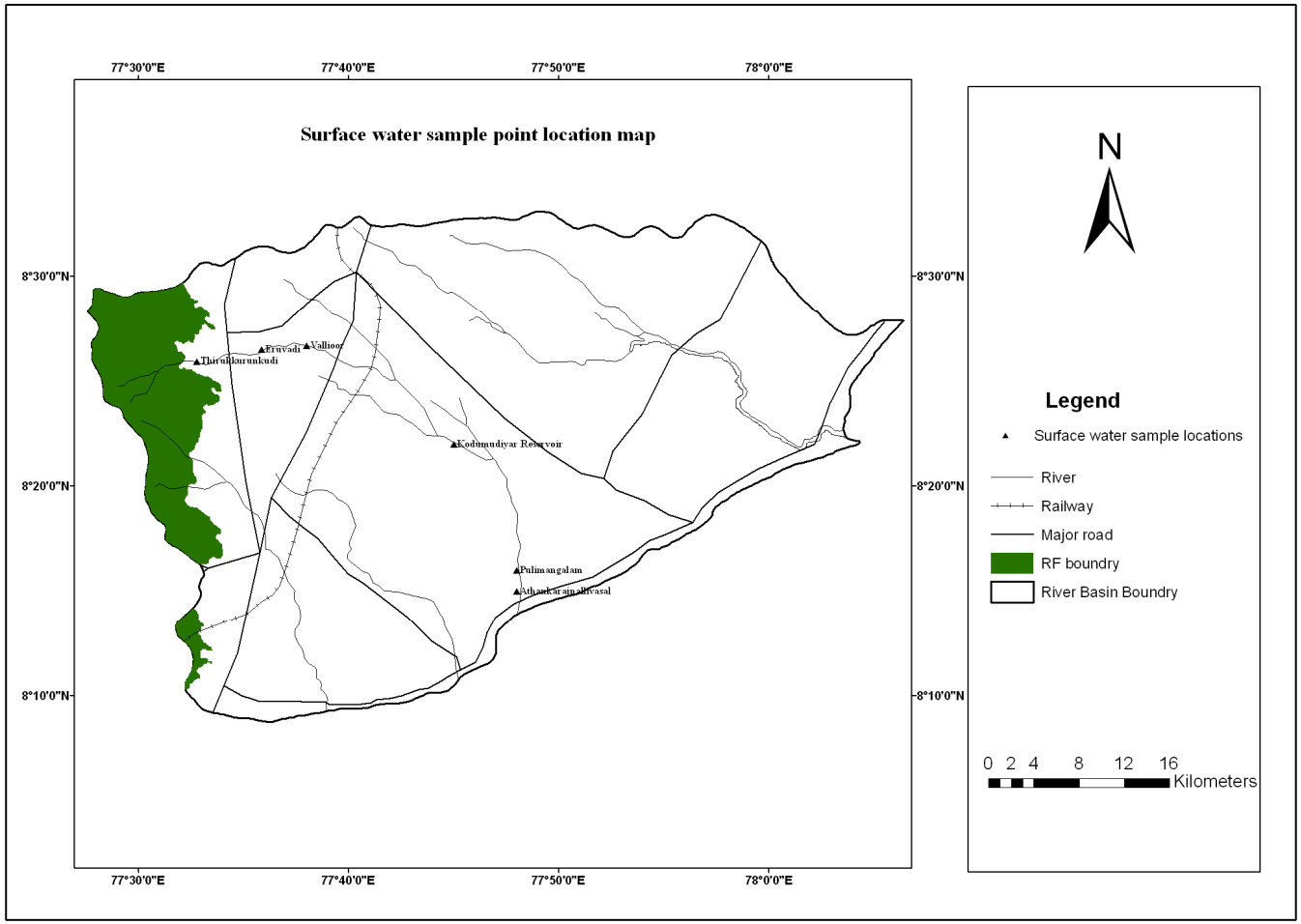


Figure 6.1 Sample Point Location Map for Surface Water Quality Trend Study

The Minimum, Maximum, Mean, Standard Error, Standard Deviation, and Variance are given in Table 6.1. The majority of the samples of the study area are found to be alkaline. The pH values are obtained with the mean value of 8.76 and the minimum and maximum as 8 and 9.3 respectively. This range is slightly more than the limits prescribed by WHO (1984) for water used in domestic applications.

Table 6.1 Descriptive Statistics for Surface Water Quality Parameters

Parameters	Minimum	Maximum	Mean	Std. Error	Std. Deviation	Variance
DO	2.83	8.66	5.8	0.71	2.01	4.03
Temperature	27	29	28.25	0.25	0.71	0.5
pH	8	9.3	8.76	0.18	0.5	0.25
EC	1.12	160	23.91	19.5	55.08	3033.98
TDS	0.04	20	6.28	2.62	7.41	54.98
TSS	0.6	103	28.62	15.3	43.14	1860.87
NO_3+NO_2 as N	0.54	8.72	2.55	1.21	3.42	11.68
BOD	0	1.98	0.89	0.24	0.68	0.46
COD	2	20	11.25	2.83	8	63.93
Total Hardness	22	220	171.8	23.7	67.14	4507.93
Ca^{++}	8.02	67.3	36.59	6.63	18.76	351.86
Mg^{++}	15.1	96.3	55.03	9.33	26.38	696.04
Cl	34.1	52.5	44.01	2.71	7.66	58.61
SO_4^{2-}	0.01	118	53.1	20.3	57.28	3281.5
HCO_3^-	20	250	138.4	29	82.12	6743.41
Total MPN	2	30	10.9	3.75	10.62	112.76
Faecal	2	13	3.91	1.33	3.78	14.25

All values are in mg/L; Except Temperature – Degree Celsius; pH - unitless; EC - umho/cm; Total MPN/100 ml; Faecal, MPN/100 ml

The DO of the basin is between 2.83 and 8.66 mg/L. It is highly suitable for fishery. Total hardness of all water samples is within the permissible limit according to WHO, ICMR, and BIS, ranging from 22 to 220 mg/L as $CaCO_3$ equivalent. The amount of calcium varies from 8.02 to 67.3 mg/L as $CaCO_3$ equivalent. So all water sample have Ca^{++} concentration within the permissible limit prescribed by WHO, ICMR, and BIS.

It is observed from Table 6.2, that the pH has significant correlation ($0.5 < r < 0.7$) with BOD, COD, Total hardness, HCO_3, and Total MPN, but poor correlation with other parameters. The poor correlation of electrical conductivity with pH as well as total dissolved solids indicates a low dissociation capacity of the dissolved solids (Jeyaraj et al.. 2001). The study area is known for heavy agricultural activities. The soluble salts, used for fertilizing the land, would be the reason for the strong correlation between TDS and SO_4. The Sulphate content lies between the permissible value for domestic and industrial applications. It showed significant correlation between TDS and Ca^{++}. The distribution of Nitrate indicates that levels of concentration of the ion are very low compared to the prescribed limit.

The amount of variation in the dependent variable that is accounted for by variation in the predictor variable is measured by the value of coefficient of determination, often called R^2 adjusted. The closer this is to 1 the better, because if R^2 adjusted is 1 then the regression model is accounting for all the variation in regression analysis, according to both by Altman (1991) and Cambell and Machin (1993). In this study most of the R^2 values are found to be significant. So the equations obtained as regression equations are reliable.

Table 6.2 Correlation Coefficients among Various Surface Water Quality Parameters

	DO	Tempt	pH	EC	TDS	TSS	N	BOD	COD	T.Hard	Ca^{++}	Mg^{++}	Cl	SO_4^{2-}	HCO_3^-	MPN	Fecal
DO	1.0000																
Tempt	0.3179	1.0000															
pH	-0.8119	0.0306	1.0000														
EC	0.0164	0.4097	0.4385	1.0000													
TDS	0.0773	-0.3401	0.1871	0.1738	1.0000												
TSS	0.0656	-0.1669	0.0512	-0.2018	0.7741	1.0000											
N	-0.8515	-0.2446	0.4756	-0.2094	-0.5110	-0.3774	1.0000										
BOD	-0.4151	-0.4900	0.5471	0.0296	0.8392	0.6557	-0.0187	1.0000									
COD	-0.1093	-0.0126	0.5472	0.4112	0.8575	0.6274	-0.4023	0.8175	1.0000								
T.Hard	-0.6487	-0.1128	0.6919	0.2620	-0.0266	0.0132	0.4029	0.2199	0.2455	1.0000							
Ca^{++}	-0.3992	-0.2873	-0.0664	-0.1949	-0.7050	-0.7089	0.7438	-0.4741	-0.7945	0.0838	1.0000						
Mg^{++}	0.4354	0.7318	-0.0075	0.6180	-0.2248	-0.4947	-0.4099	-0.4147	0.0743	-0.1885	-0.2250	1.0000					
Cl	-0.1615	0.4110	0.0649	0.3181	-0.7112	-0.7072	0.5089	-0.5954	-0.5889	-0.1132	0.6410	0.3295	1.0000				
SO_4^{2-}	0.0819	-0.1118	0.3125	0.2700	0.9211	0.6672	-0.5760	0.7799	0.9532	0.0781	-0.8233	0.0460	-0.7421	1.0000			
HCO_3^-	-0.3129	0.0646	0.6190	0.1948	0.2983	0.2540	0.0384	0.5591	0.6223	0.4239	-0.5175	0.1080	-0.2920	0.4543	1.0000		
MPN	-0.4044	-0.0152	0.5066	0.2263	-0.0231	-0.3978	0.1811	0.1586	0.2399	0.2880	0.1321	0.3407	-0.0337	0.2327	0.1140	1.0000	
Faecal	-0.6429	-0.0977	0.3584	0.0322	-0.3700	-0.3367	0.6750	-0.1661	-0.3234	0.3911	0.6947	-0.2524	0.4271	-0.3950	-0.4588	0.4164	1.0000

The study helps in predicting probable compositional structure and their interdependence. The correlation co-efficient determination will greatly ease the tasks of rapid monitoring of water quality parameters sans any cost. Planning and designing of water resources projects need information on different hydrologic events that are not governed by the known physical and chemical laws, but are governed by the laws of chance. The statistical analysis of the experimentally estimated water quality parameters on water samples yielded values of the Range, Minimum, Maximum, Mean, Standard Error, Standard Deviation, and Variance. Since the correlation coefficients give the interrelationships between the parameters, correlation coefficients were calculated. The parameters which have strong correlation are, between pH and DO as shown in Figure 6.2 and Table 6.3, N and DO as shown in Figure 6.3 and Table 6.4, TDS and SO_4 as shown in Figure 6.4 and Table 6.5, Ca^{++} and SO_4 as shown in Figure 6.5 and Table 6.6, TDS and COD as shown in Figure 6.6 and Table 6.7. There is a strong correlation between SO_4 and COD as shown in Figure 6.7 and Table 6.8. The suitable regression equations have been formed for these pairs of values in the study area. The highest positive correlation ($r = 0.9532$) is found between SO_4 and COD.

The calculated values for the surface water quality parameters, using the regression equations developed have been compared with the observed values are shown in Figure 6.2 to Figure 6.8 and Table 6.3 to 6.9. There is variation in the values but the trend is the same as that of the calculated values. It is found that TDS with Sulphate and COD have better positive correlation, Sulphate with Ca^{++} and COD also having positive correlation and pH with DO and N with DO have better negative correlation. Hence by making measurement of the TDS concentration of better related parameters, like SO_4, COD can be estimated (Ibrahim and Saseetharan 2006). From the descriptive statistical analysis, it is found that most of the water quality parameters are within the permissible limits of BIS. This may therefore be

treated as rapid method of water quality monitoring. Measuring TDS with portable TDS meter, other parameters can be reckoned at the site itself using the developed equations for preliminary studies during planning (Mariappan and Vasudevan 2002).

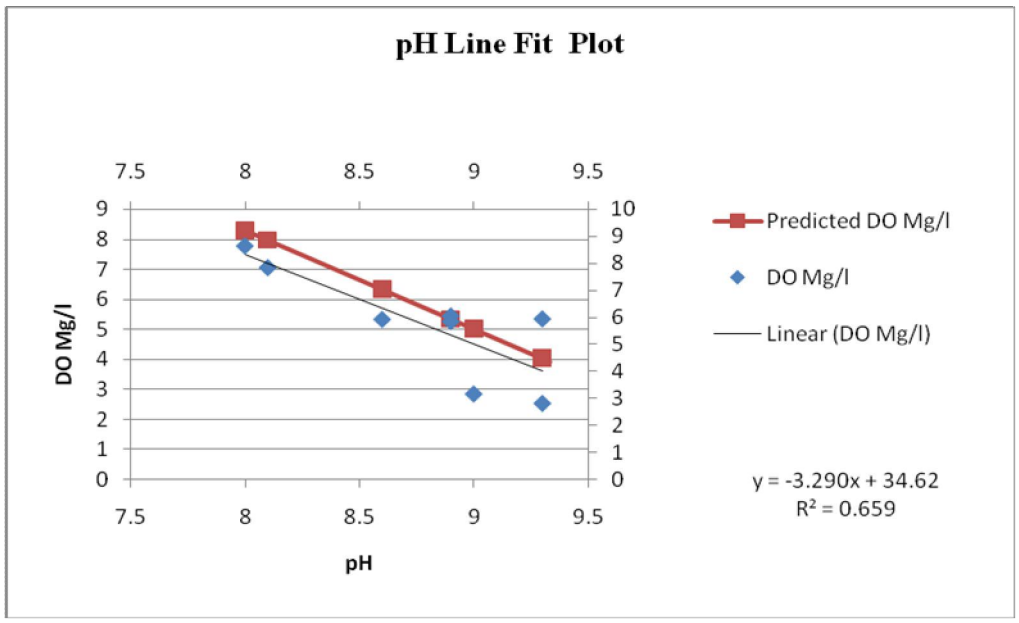


Figure 6.2 Regression between pH and DO

Table 6.3 Regression Summary Output - pH and DO

Regression Statistics	
Multiple R	0.8119
R Square	0.6592
Adjusted R Square	0.6024
Standard Error	1.2663
Observations	8.0000

ANOVA					
	df	SS	MS	F	Significance F
Regression	1.0000	18.6093	18.6093	11.6057	0.0144
Residual	6.0000	9.6207	1.6035		
Total	7.0000	28.2300			

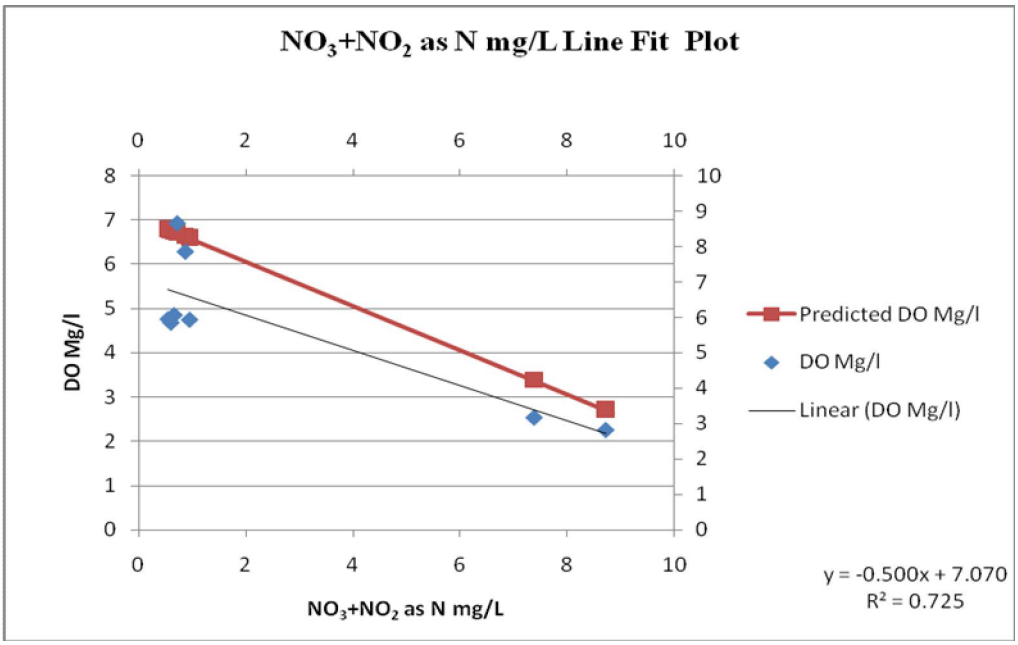


Figure 6.3 Regression between NO_3+NO_2 as N and DO

Table 6.4 Regression Summary Output - NO_3+NO_2 as N and DO

Regression Statistics	
Multiple R	0.85154
R Square	0.72512
Adjusted R Square	0.679307
Standard Error	1.137237
Observations	8

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	20.47015	20.47015	15.82773	0.007296
Residual	6	7.759853	1.293309		
Total	7	28.23			

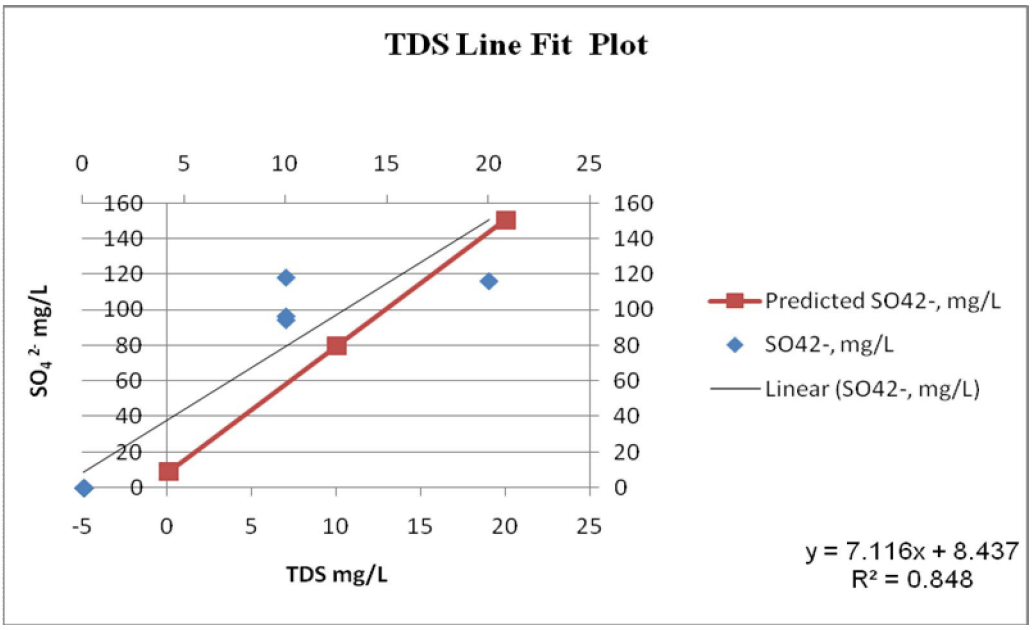


Figure 6.4 Regression between TDS and SO_4

Table 6.5 Regression Summary Output - TDS and SO_4

Regression Statistics	
Multiple R	0.921132
R Square	0.848485
Adjusted R Square	0.823232
Standard Error	24.08452
Observations	8

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	19490.1	19490.1	33.59991	0.001155
Residual	6	3480.384	580.064		
Total	7	22970.48			

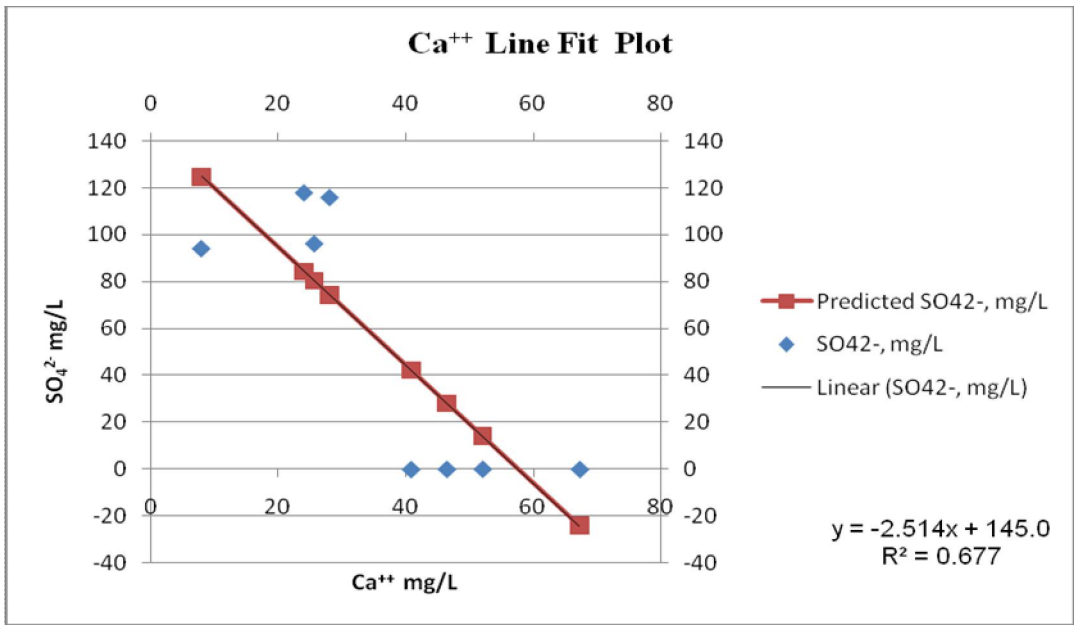


Figure 6.5 Regression between Ca^{++} and SO_4

Table 6.6 Regression Summary Output - Ca^{++} and SO_4

Regression Statistics	
Multiple R	0.82326
R Square	0.677757
Adjusted R Square	0.62405
Standard Error	35.12376
Observations	8

ANOVA					
	df	SS	MS	F	Significance F
Regression	1.0000	15568.4126	15568.4126	12.6195	0.0120
Residual	6.0000	7402.0696	1233.6783		
Total	7.0000	22970.4822			

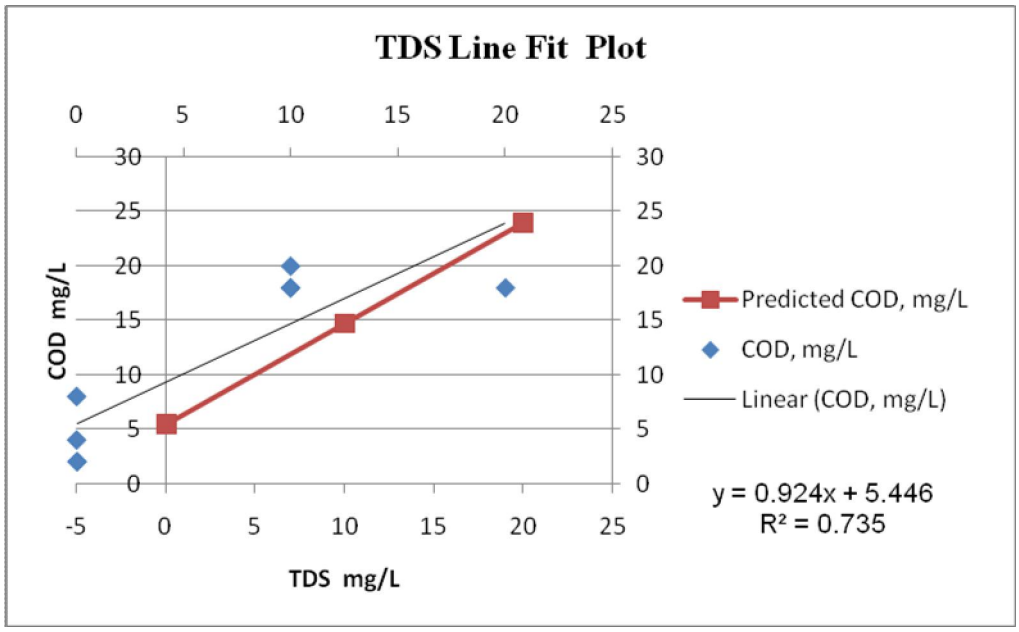


Figure 6.6 Regression between TDS and COD

Table 6.7 Regression Summary Output - TDS and COD

Regression Statistics	
Multiple R	0.857513
R Square	0.735328
Adjusted R Square	0.691216
Standard Error	4.442982
Observations	8

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	329.0595	329.0595	16.6696	0.006481
Residual	6	118.4405	19.74009		
Total	7	447.5			

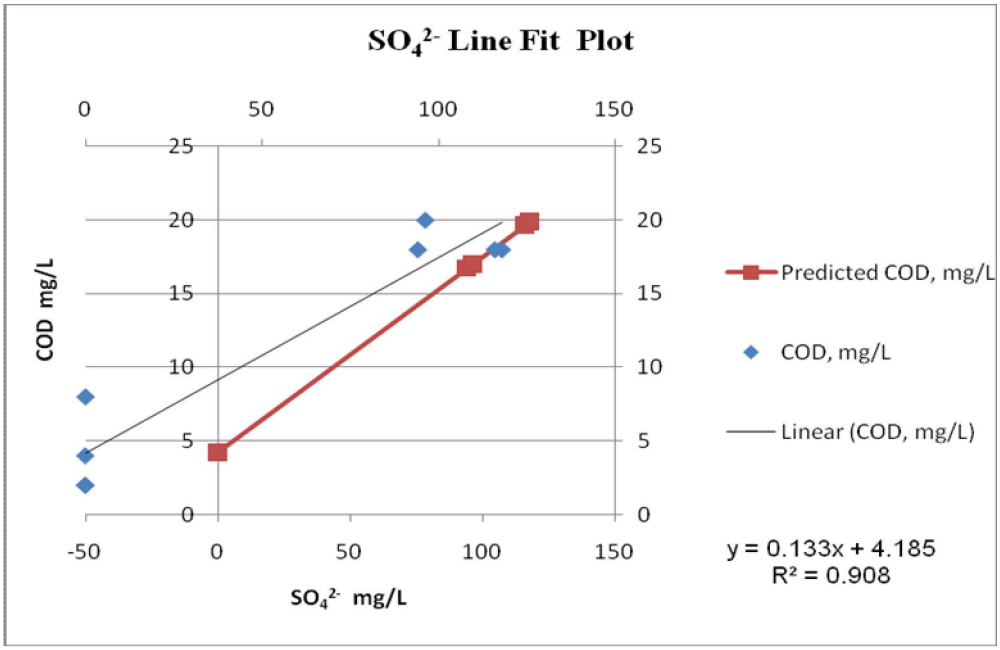


Figure 6.7 Regression between SO_4 and COD

Table 6.8 Regression Summary Output - SO_4 and COD

Regression Statistics	
Multiple R	0.953217
R Square	0.908622
Adjusted R Square	0.893393
Standard Error	2.610606
Observations	8

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	406.6084	406.6084	59.66146	0.000247
Residual	6	40.89157	6.815262		
Total	7	447.5			

The regression analysis equations for the different surface water quality parameters are given in the Table 6.9.

Table 6.9 Regression Equations for Surface Water Quality Parameters

Sl. No	Parameters	R value	Regression equation
1.	pH & DO	0.6592	Y = -3.2905 x + 34.268
2.	NO_3 + NO_2 & DO	0.7251	Y = -0.5005 x + 7.0706
3.	TDS & SO_4	0.8485	Y = 7.1161 x + 8.4374
4.	Ca^{++} & SO_4	0.6778	Y = -2.514 x + 145.08
5.	TDS & COD	0.7353	Y = 0.9246 x + 5.4467
6.	SO_4 & COD	0.9086	Y = 0.133 x + 4.1852

6.2 WATER QUALITY TREND STUDY FOR GROUNDWATER

Statistical investigation offers more attractive options in environmental science, though the results may deviate more from real situations. The correlation provides an excellent tool for the prediction of parametric values within a reasonable degree of accuracy (Venkatachalam and Jebanesan 1998). The quality of water is described by its physical, chemical and microbial characteristics. But, if some correlations are possible among these parameters, then the more significant ones would be useful to indicate fairly the quality of water (Dhembare and Pondhe 1997). Ground water is one of the earth's widely distributed, renewable and most important resources. It is generally considered least polluted compared to other inland water resources, but studies indicate that ground water is not absolutely free from pollution though it is likely to be free from suspended solids. The major problem with the ground water is that once contaminated, it is difficult to

restore its quality. Hence there is a need and concern for the protection and management of ground water quality. It is well known that no straight forward reasons can be advanced for the deterioration of water quality, as it is dependent on several water quality parameters. A systematic study of correlation and regression coefficients of the quality parameters not only helps to assess the overall water quality but also to quantify relative concentration of various pollutants in water and provide necessary cue for implementation of rapid water quality management programmes (Dash et al 2006).

The main objective of this study is to make a statistical trend analysis of groundwater quality of the Nambiyar River basin, viz., Mean, Median, Mode, Maximum, Minimum and Standard Deviation of the pollution parameters, and more importantly, finding the Regression equations between the significantly correlated water quality parameters ($0.8 < r < 1.0$).

The correlation coefficients among all the groundwater quality characteristics have been calculated. The data from Tamil Nadu Public Works Department's monitoring well were used for statistical analysis for the years 1998, 1999, 2002 and 2003. The Sample point location details are given in the Figure 6.8 and the sample point ID details are given in Table 6.10. The correlation analysis on water quality parameters reveals that all the parameters are reasonably correlated with each other.

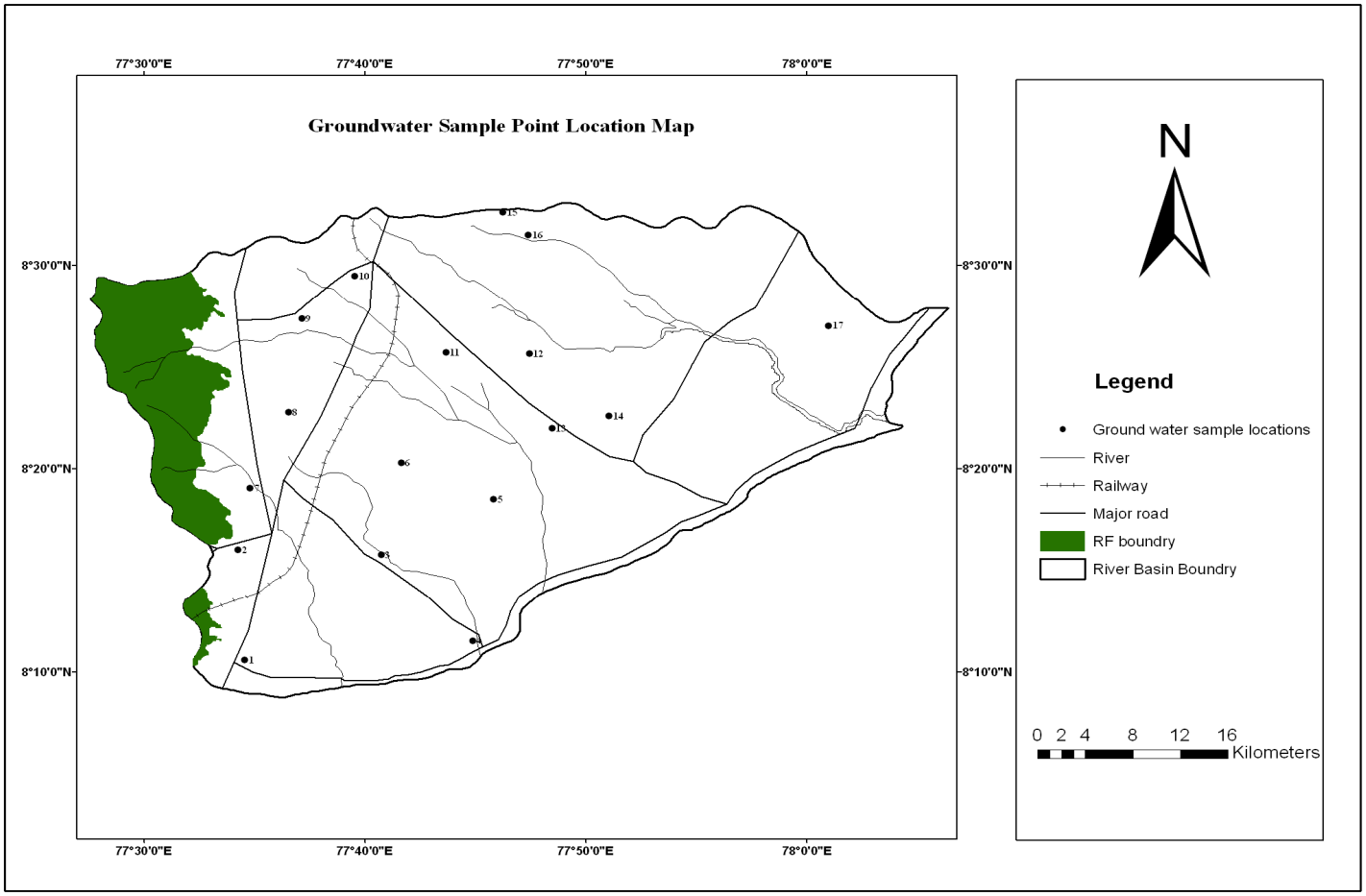


Figure 6.8 Sample Point Location Map for Groundwater Quality Trend Study

Table 6.10 Groundwater Sample points location ID Details

Place	Sample Point ID	Place	Sample Point ID
Karungulam	1	Nanguneri	10
Kavalkinaru	2	Parapadi	11
Radhapuram	3	Vijayanarayanam	12
Vijayapathi	4	Mannarpuram	13
Kasturirangapuram	5	Ittamoli	14
Samuharangapuram	6	Moolakaraipatti	15
Panagudi	7	Munaijipatti	16
Valliyoor	8	Udangudi	17
Alankulam	9		

Results of the present investigation like, Minimum, Maximum, Mean, Mode, Standard Deviation (SD), Range and Confidential interval are presented in Table 6.11. Average values of all the water quality parameters have been obtained with 95% Confidence Level. It is observed from the pH value that water samples are slightly alkaline from (7.4 to 8.7) as the median value of 8.10 of the basin. The values are within the highest desirable limits of WHO, ICMR and BIS.

The mean and mode values of the Total Dissolved Solids (TDS) of all water samples are 927.58 mg/l and 195 mg/l respectively, which shows that the TDS of the basin water quality is high compared with the WHO standard value. All the samples analyzed are free from Sulphate pollution as

SO_4 content varies from 0 to 392 mg/l, which is within the permissible limit according to WHO, ICMR and BIS.

Ca varies from a minimum of 8 mg/l to a maximum of 660 mg/l which is higher than the permissible values given by the all three organizations. Carbonate hardnesses by HCO_3 and CO_3 are within the prescribed values given by the WHO, ICMR and BIS. The Cl concentration in the basin is in the higher level compared with WHO, ICMR and BIS.

Table 6.11 Statistical Parameters of Groundwater Qualities

Statistical Parameters	EC	pH	Ca	N	Na	K	HCO_3	CO_3	SO_4	Cl	TDS
Mean	1738.42	8.11	84.31	46.88	130.15	13.17	182.69	11.39	70.64	396.14	927.58
Standard Error	285.81	0.04	14.31	5.75	17.71	2.15	11.65	2.49	10.44	84.28	139.23
Median	1180.00	8.10	50.00	32.00	92.00	7.00	165.00	0.00	43.00	181.00	601.00
Mode	480.00	8.00	20.00	23.00	46.00	8.00	85.00	0.00	43.00	71.00	195.00
Standard Deviation	2195.31	0.29	109.89	44.13	136.01	16.51	89.46	19.09	80.20	647.38	1069.47
Range	11430.00	1.30	652.00	170.00	687.00	88.00	409.00	72.00	392.00	4063.00	6555.00
Minimum	100.00	7.40	8.00	1.00	3.00	2.00	24.00	0.00	0.00	14.00	60.00
Maximum	11530.00	8.70	660.00	171.00	690.00	90.00	433.00	72.00	392.00	4077.00	6615.00
Count	59.00	59.00	59.00	59.00	59.00	59.00	59.00	59.00	59.00	59.00	59.00
Confidence Level(95.0%)	572.10	0.07	28.64	11.50	35.44	4.30	23.31	4.98	20.90	168.71	278.71

(*All values Except EC and pH are in mg/l; pH - unitless; EC - umho/cm*)

The EC value gives the mean value of 1738.42 umho/cm. Since there is no standard value prescribed for drinking purpose by WHO, ICMR and BIS, no comparison can be made from observed values.

The Correlation coefficients (r) among various water quality parameters have been calculated and the numerical values of Correlation coefficients are tabulated in Table 6.12.

Out of the 66 Correlation coefficients, 6 Correlation coefficients (r) between the TDS and Cl (0.986831), TDS and Ca (0.91798), Cl and Ca (0.903641), TDS and SO_4 (0.853032), TDS and Na (0.812696), SO_4 and Ca (0.800936) are found to be with highly significant levels ($0.8 < r < 1.0$), 11 correlation coefficients are at the moderately significant levels ($0.6 < r < 0.8$) and 4 correlation coefficients give the significant ($0.5 < r < 0.6$) levels.

Table 6.12 Correlation Coefficients among Various Groundwater Quality Parameters

Parameters	EC	pH	Ca	N	Na	K	HCO_3	CO_3	SO_4	Cl	TDS
EC	1.0000										
pH	-0.0943	1.0000									
Ca	0.7328	-0.1475	1.0000								
N	0.4184	-0.1435	0.3927	1.0000							
Na	0.6216	-0.2151	0.6092	0.4087	1.0000						
K	0.4439	-0.3768	0.3906	0.4685	0.5855	1.0000					
HCO_3	0.1257	0.0426	0.0604	0.1138	0.0259	-0.1892	1.0000				
CO_3	-0.0482	0.6827	-0.0109	0.1282	-0.1141	-0.1099	0.0845	1.0000			
SO_4	0.6571	-0.1978	0.8009	0.5480	0.7321	0.6037	0.0727	-0.0168	1.0000		
Cl	0.7859	-0.2142	0.9036	0.4185	0.7663	0.5553	-0.1295	-0.0915	0.7859	1.0000	
TDS	0.7975	-0.2096	0.9180	0.4824	0.8127	0.5849	-0.0250	-0.0583	0.8530	0.9868	1.0000

The regression analysis equations for the different water quality parameters are given in the Table 6.13.

Table 6.13 Regression Equations for Groundwater Quality Parameters

Sl. No.	Regression Equations
1.	TDS = 1.6302 Cl + 281.78
2.	TDS = 7.9588 Ca + 688.79
3.	Cl = 4.8821 Ca + 249.67
4.	TDS = 2.2896 SO_4 + 858.89
5.	TDS = 11.144 Na + 593.27
6.	SO_4 = 0.5361 Ca + 54.562

The calculated values for the groundwater quality parameters, using the regression equations have been compared with the observed values like, TDS with Cl as shown in Figure 6.9, TDS with Ca as shown in Figure 6.10, Cl with Ca as shown in Figure 6.11, TDS with SO_4 as shown in Figure 6.12, TDS with Na as shown in Figure 6.13, SO_4 with Ca as shown in Figure 6.14. The regression summary output and error in the statistical calculation have been presented in Table 6.14 to 6.19.

As this is a statistical calculation, deviations and errors are likely to be present; however in spite of errors this method is very useful, because analysis of all parameters is very costly and time-consuming. Results of correlation analysis show that TDS and Chlorine present high correlation with other parameters. Since the Total Dissolved Solids gives high correlation with Chlorine, Calcium, Shulphate and Sodium, regression equation relating TDS and these parameters have been formulated. Hence by making measurement

of the TDS, concentration of the better related parameters, like Chlorine, Calcium, Shulphate and Sodium can be estimated. This method thus gives a superior alternative. This approach is useful in detecting changes in water quality within the system.

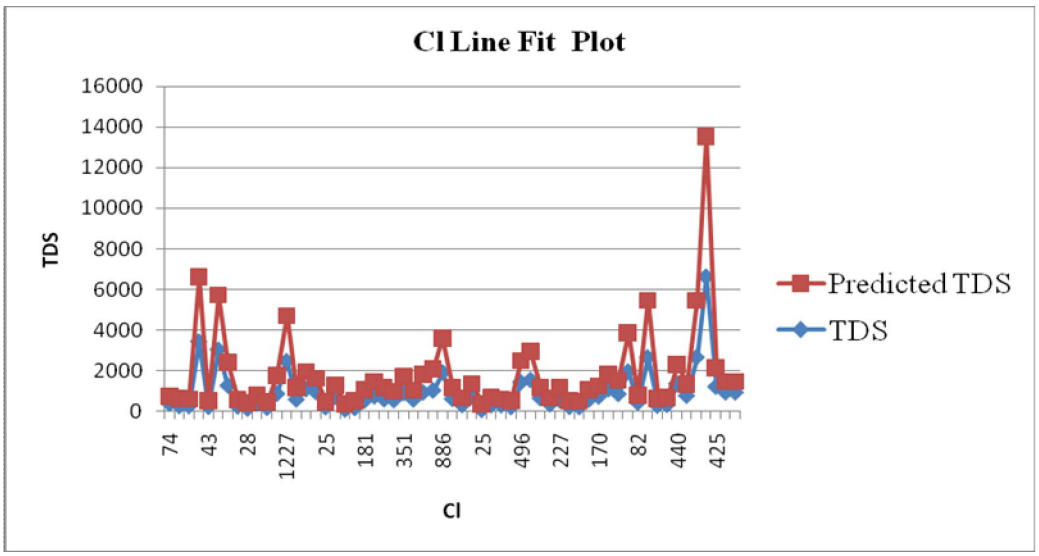


Figure 6.9 Regression between TDS and Cl

Table 6.14 Regression Summary Output - TDS and Cl

Multiple R	0.986831097
R Square	0.973835614
Adjusted R Square	0.97337659
Standard Error	174.5019738
Observations	59

ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	64602696.89	64602696.89	2121.533829	8.55871E-47
Residual	57	1735703.514	30450.93885		
Total	58	66338400.41			

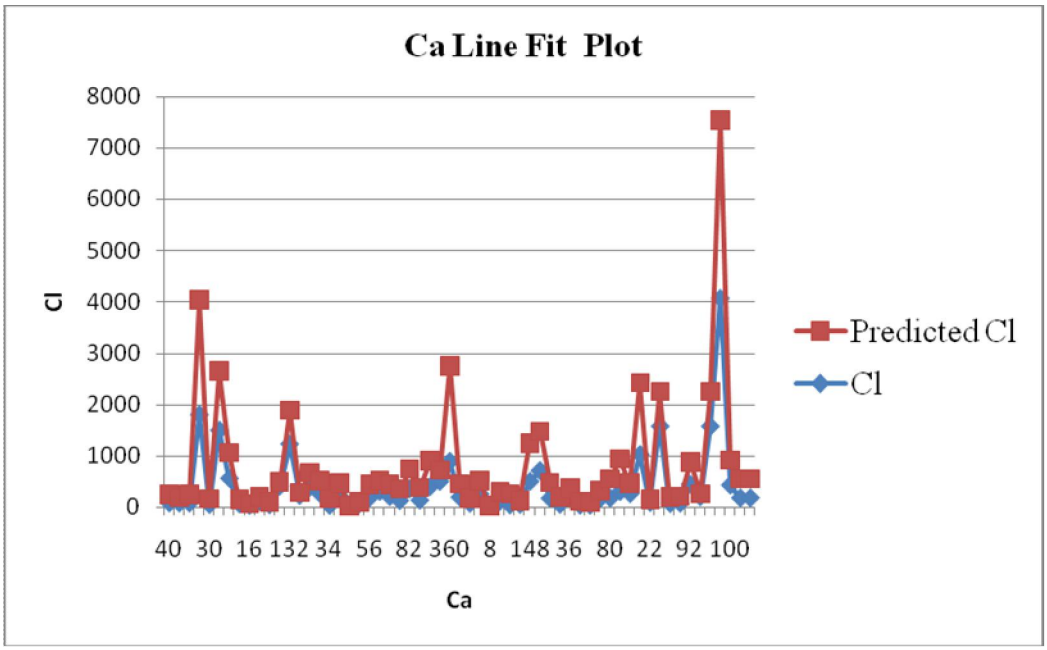


Figure 6.10 Regression between TDS and Ca

Table 6.15 Regression summary Output - TDS and Ca

Multiple R	0.917980267
R Square	0.842687771
Adjusted R Square	0.839927908
Standard Error	427.8842606
Observations	59

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	55902559	55902559	305.3367	1.46E-24
Residual	57	10435842	183084.9		
Total	58	66338400			

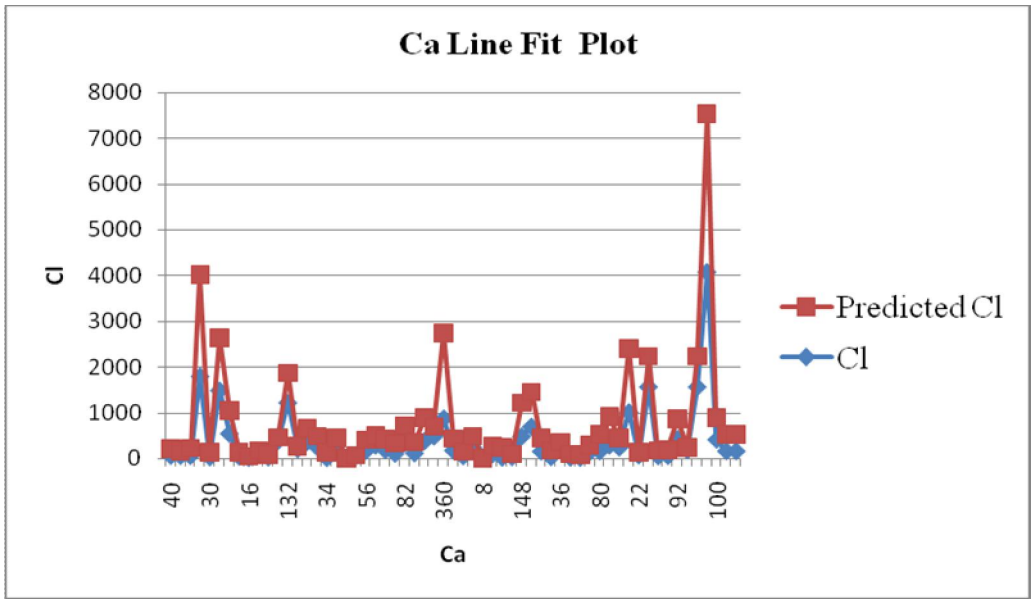


Figure 6.11 Regression between Cl and Ca

Table 6.16 Regression Summary Output - Cl and Ca

Multiple R	0.903640549
R Square	0.816566242
Adjusted R Square	0.813348106
Standard Error	279.6896511
Observations	59

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	19849054	19849054	253.7389	1.18E-22
Residual	57	4458899	78226.3		
Total	58	24307953			

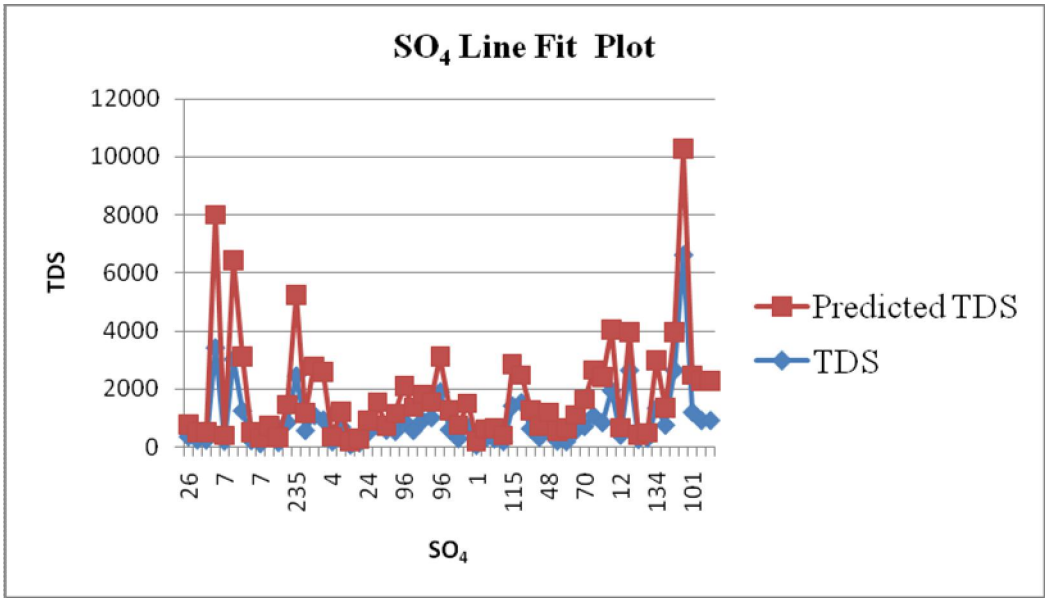


Figure 6.12 Regression between TDS and SO_4

Table 6.17 Regression summary Output - TDS and SO_4

Multiple R	0.853032
R Square	0.727663
Adjusted R Square	0.722885
Standard Error	562.987
Observations	59

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	48272001	48272001	152.2995	9.75E-18
Residual	57	18066400	316954.4		
Total	58	66338400			

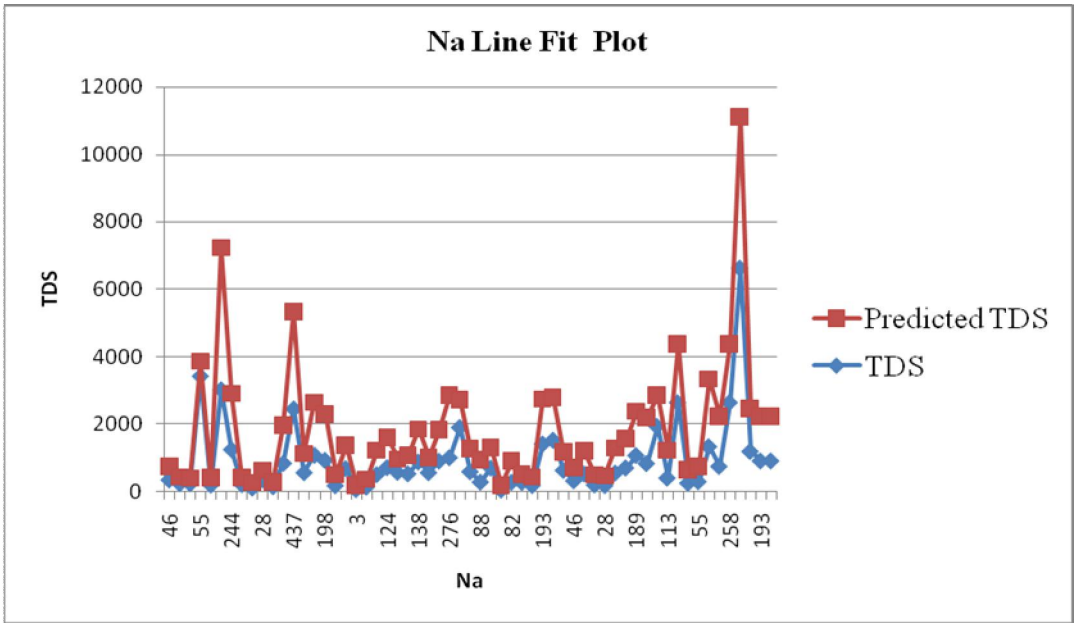


Figure 6.13 Regression between TDS and Na

Table 6.18 Regression summary Output - TDS and Na

Multiple R	0.8126956
R Square	0.6604741
Adjusted R Square	0.6545175
Standard Error	628.61032
Observations	59

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	43814797	43814797	110.88117	5.474E-15
Residual	57	22523603	395150.94		
Total	58	66338400			

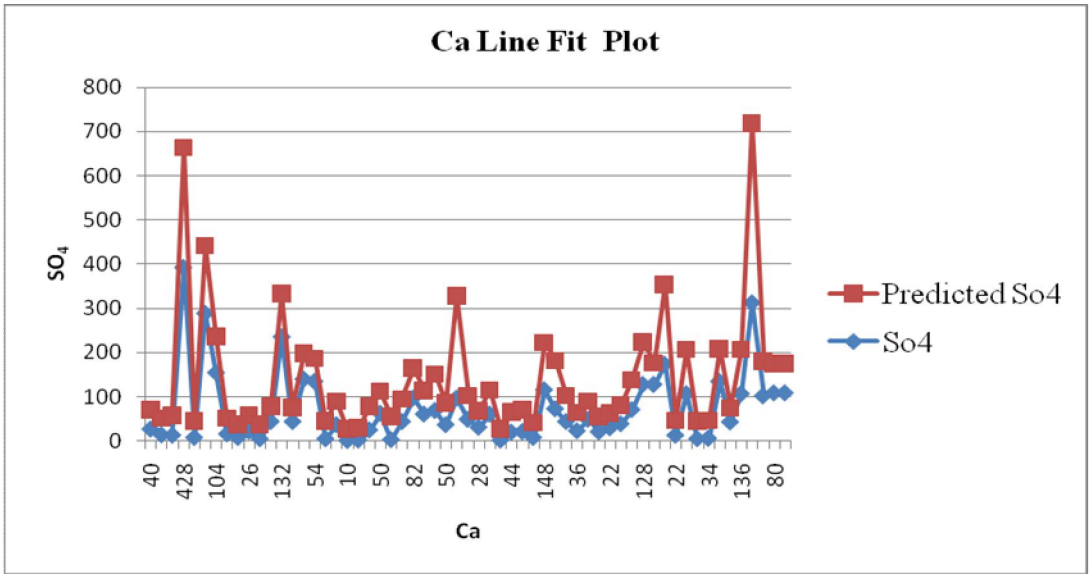


Fig. 6.14 Regression between SO_4 and Ca

Table 6.19 Regression Summary Output - SO_4 and Ca

Multiple R	0.8009358
R Square	0.6414982
Adjusted R Square	0.6352087
Standard Error	48.439889
Observations	59

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	239323.4	239323.4	101.995	2.62E-14
Residual	57	133746.1	2346.423		
Total	58	373069.5			

Indirect method of evaluation of ground water quality presented in this thesis provides a better alternative for a systematic study over the conventional techniques. It reduces the quantum of analysis, as well as time. This may be therefore treated as a rapid method of water quality monitoring for the Nambiyar River basin.

6.3 STATISTICAL STUDY ON GROUNDWATER QUALITY

Based on detailed well inventory survey in Nambiyar River basin, 32 representative groundwater wells (created by Tamil Nadu Public Works Department, Government of Tamil Nadu, for regular monitoring of water quality) were selected for groundwater sampling program. The sample point locations are shown in Figure 6.15, and location ID details are given in Table 6.20. The groundwater sampling campaigns were carried out from the 32 representative wells during January 2009 and July 2009. Field parameters such as electrical conductivity, pH, and temperature were measured in the field using portable meters. Water samples collected in the field were analyzed for chemical constituents, such as Calcium, Magnesium, Sodium, Potassium, Bicarbonate, Carbonate, and Chloride, in the laboratory using the standard methods as suggested by the American Public Health Association (1989 and 1995).

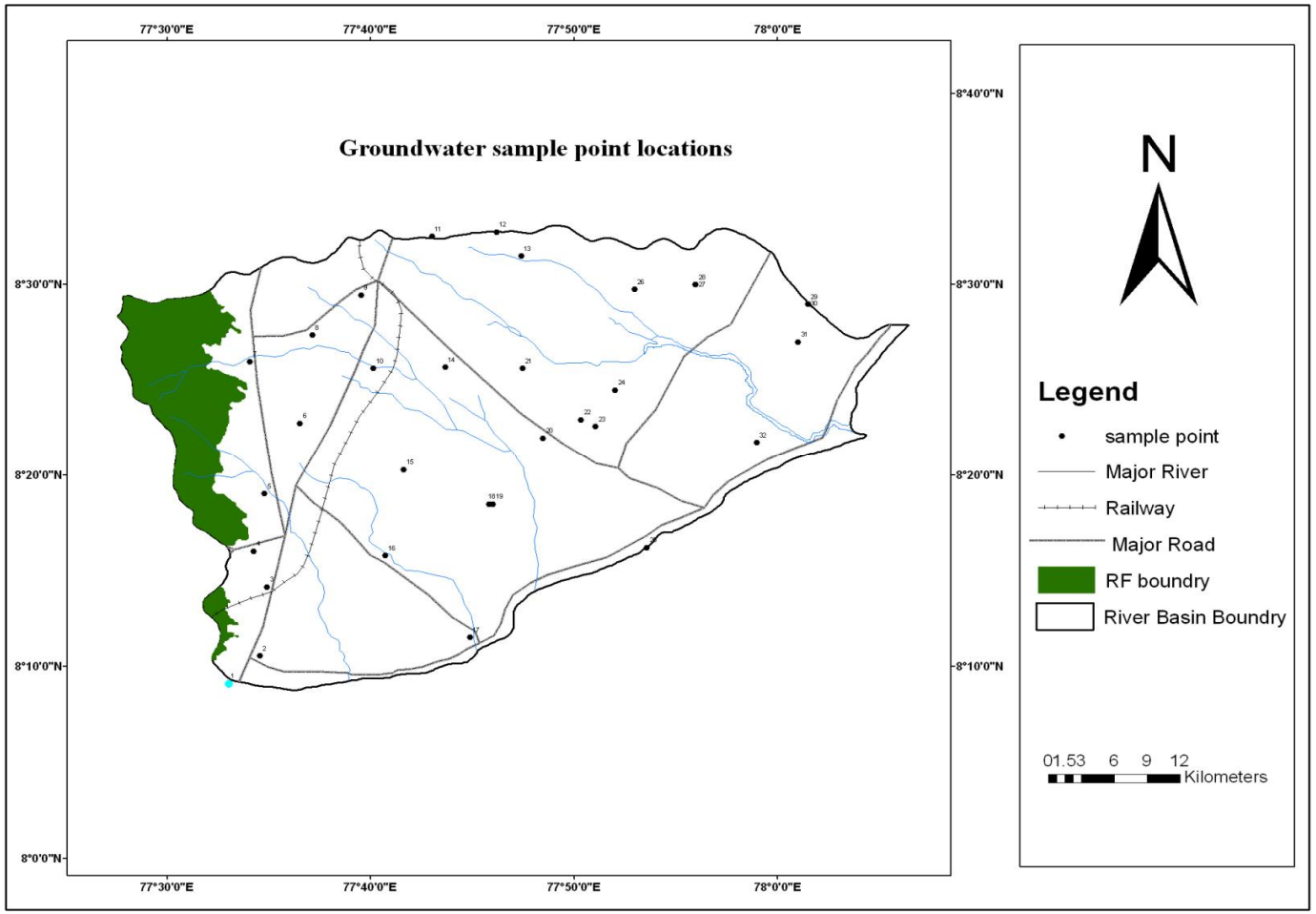


Figure 6.15 Sample Points Location Map for Groundwater Quality Statistical Study

Table 6.20 Groundwater Sample Points Location ID Details

Station Name	ID	Station Name	ID
Bagavathipuram	1	Vijayapathi	17
Karunkulam	2	Kausturirangapuram	18
Soundaralingapuram	3	Kasturirangapuram (a)	19
Kavalkinar	4	Mannarpuram vilakku	20
Panagudi	5	Vadakku Vijayanarayanam	21
Valliyoor	6	Ittamozhipudur	22
Tirukkurungudi	7	Ittamozhi	23
Alangulam	8	Pudukulam	24
Nanguneri	9	Uvari	25
Tulukkarpatti	10	Karunkadal	26
Unnankulam	11	Anandapuram	27
Moolaikaraipatti	12	Ananda_puram	28
Munanjipatti	13	Tiruchendur	29
Parappadi	14	Sundarapuram	30
Samugarengapuram	15	Udankudi	31
Radhapuram	16	Padukkapathu	32

The normal statistics of groundwater quality parameters are given in Table 6.21. Electrical Conductivity of water is a direct function of its total dissolved salts (Harilal et al 2004). Hence it is an index to represent the total

concentration of soluble salts in water (Purandara et al 2003). In the study area, the electrical conductivity of the ground water samples varied between 200 to 10110 µS/cm in pre-monsoon and 180 to 6000 in post-monsoon periods. The permissible total dissolved salts for drinking water is 500 mg/l, in the absence of potable water source the permissible limit is up to 2000 mg/l. It is found from the analysis that the entire well water sample TDS is beyond the permissible limits in few places in both pre-monsoon as well as in post-monsoon seasons. The range of TDS levels in the study area is 90-4634 mg/l. The highest concentration of total dissolved solids was found to be 5531 mg/l in the pre-monsoon period at Munanjipatti and 3737 mg/l at VadakkuVijayanarayanam due to high residential concentration and intensive irrigation in that area.

Table 6.21 Summary of Groundwater Quality Parameters

Parameters		EC	pH	TDS	Hardness	Ca	Mg	Na	K	HCO_3	CO_3	Cl	SO_4	NO_3	F
Units	-	**µS/cm**		**ppm**											
Pre-Monsoon	Minimum	200.00	7.20	65.00	134.00	9.00	1.00	3.00	2.00	32.00	5.00	7.00	22.00	0.05	0.13
	Maximum	10110.00	9.00	5531.00	4700.00	720.00	204.70	782.00	41.00	732.00	84.00	3332.00	365.00	119.00	0.90
	Mean	2269.69	8.05	1305.13	620.00	122.63	60.56	234.88	10.63	212.67	5.93	555.31	101.59	20.31	0.37
	Median	1700.00	8.00	1019.50	380.00	85.00	34.63	177.50	6.00	205.33	0.00	319.00	69.50	11.00	0.35
	Standard deviation	2091.00	0.34	1213.35	848.65	141.42	56.95	207.00	11.13	133.15	18.57	684.25	99.36	26.93	0.27
Post-monsoon	Minimum	180.00	7.70	115.00	80.00	18.00	5.00	5.00	2.00	49.00	0.00	18.00	7.00	0.00	0.00
	Maximum	6000.00	9.50	3737.00	1800.00	296.00	353.00	874.00	117.00	567.00	90.00	1787.00	298.00	151.00	0.30
	Mean	1913.63	8.49	1197.34	520.00	89.00	72.12	233.38	22.69	219.71	18.00	463.44	96.41	21.59	0.01
	Median	1680.00	8.50	999.50	365.00	59.00	51.50	207.00	12.50	180.00	12.00	377.50	84.00	10.00	0.00
	Standard deviation	1511.63	0.56	953.79	408.86	80.40	70.93	206.40	26.57	132.14	22.50	446.99	88.79	34.75	0.05
Total	Minimum	190.00	7.45	90.00	107.00	13.50	3.00	4.00	2.00	40.50	2.50	12.50	14.50	0.03	0.07
	Maximum	8055.00	9.25	4634.00	3250.00	508.00	278.85	828.00	79.00	649.50	87.00	2559.50	331.50	135.00	0.60
	Mean	2091.66	8.27	1251.23	570.00	105.81	66.34	234.13	16.66	216.19	11.96	509.38	99.00	20.95	0.19
	Median	1690.00	8.25	1009.50	372.50	72.00	43.06	192.25	9.25	192.67	6.00	348.25	76.75	10.50	0.18
	Standard deviation	1801.31	0.45	1083.57	628.75	110.91	63.94	206.70	18.85	132.64	20.54	565.62	94.08	30.84	0.16

High value of TDS in groundwater is generally not harmful to human beings but high concentration of these may affect persons who are suffering from kidney and heart diseases (Gupta et al 2004). During the pre-monsoon season, based on the comparisons of chemical constituents with WHO (1984) standards, it is found that, for 32 water samples, twelve samples have total hardness values above the maximum permissible limit of 500 mg/l. Total hardness varies from 650 to 4700 mg/l. On the other hand, during post-monsoon season, it is found that, for 32 water samples, thirteen samples have total hardness value above maximum permissible limit, and it varies from 665 to 1280 mg/l. The hardness values for the study area are found to be high for almost all locations for pre-monsoon season. Chloride is a widely distributed element in all types of rocks in one or the other form. Its affinity towards sodium is high. Therefore, its concentration is high in groundwater, where the temperature is high and rainfall is less. Soil porosity and permeability also has a key role in building up the chlorides concentration. The chloride content ranges from 18 to 3332 mg/l in pre-monsoon season and 18 to 1787 mg/l in post-monsoon season. The higher value of 3332 mg/l was found to be in Munanjipatti.

The nitrate value varies from 0.05 to 119 mg/l for the pre-monsoon period. For the post-monsoon period, the value varies from 0 to 151 mg/l. The nitrate value for the study area is found to be more than 45 mg/l as per WHO (1994) in four locations. Higher nitrate value is found in the study area due to over-application of fertilizer, improper manure management practices, and improper operation and maintenance of septic systems.

The degree of linear association between any two of the water quality parameters, as measured by the simple correlation coefficient, is presented in Table 6.22.

Table 6.22 Correlation Matrix of Groundwater Physiochemical Parameters

	pH	EC	Hard	Ca	Mg	HCO_3	CO_3	Cl	TDS	F	Na	NO_3	K
pH	1.000												
EC	-0.156	1.000											
Hard	-0.091	0.882	1.000										
Ca	-0.125	0.777	0.903	1.000									
Mg	-0.144	0.868	0.705	0.492	1.000								
HCO_3	0.039	0.445	0.364	0.252	0.451	1.000							
CO_3	0.553	0.127	0.150	0.019	0.235	0.541	1.000						
Cl	-0.213	0.656	0.377	0.266	0.768	0.340	0.065	1.000					
TDS	-0.167	0.994	0.854	0.776	0.857	0.428	0.105	0.673	1.000				
F	-0.139	0.086	-0.069	-0.192	0.231	0.177	-0.058	0.276	0.084	1.000			
Na	-0.168	0.835	0.487	0.406	0.800	0.405	0.074	0.778	0.864	0.261	1.000		
NO_3	-0.254	0.534	0.420	0.598	0.420	0.076	-0.084	0.389	0.598	-0.229	0.512	1.000	
K	-0.211	0.551	0.471	0.498	0.435	0.296	0.076	0.453	0.587	-0.159	0.473	0.596	1.000

Regression equations for the significantly correlated groundwater quality parameters have been found. The regression analysis is carried out by taking TDS as dependent variable and Hardness, Ca, Mg, HCO_3, NO_3 and SO_4 as independent variables. This may be used to predict or forecast values of the dependent variable. The regression models can be used to find out the ionic concentration of the groundwater samples, if the dependent variable TDS is measured for different location, by inverse calculations. The regression models obtained are tabulated in Table 6.23. Considering a known value of TDS, the percentage contribution of each ion can be obtained by substituting an average ionic value for the entire study area for any season.

Table 6.23 Regression Equations for Groundwater Quality Parameters

Sl. No.	Regression Equations		
1.	EC	=	1.6338 TDS + 47.42
2.	Hardness	=	0.4589 TDS – 4.1922
3.	Ca	=	0.0768 TDS + 9.6901
4.	Mg	=	0.045 TDS + 10.012
5.	HCO_3	=	0.0476 TDS + 156.63
6.	CO_3	=	0.0017 TDS + 9.8321
7.	NO_3	=	0.0191 TDS – 2.9575
8.	K	=	0.0095 TDS + 4.8083

6.4 CORRELATION ANALYSIS BETWEEN GROUNDWATER QUALITY AND SURFACE WATER QUALITY

One of the difficult tasks facing environmental mangers is have to transfer their interpretation of complex environmental data into information that is understandable and useful to technical and policy individuals as well as the general public. This is particularly important in reporting the state of the environment. Internationally, there have been a number of attempts to produce a method that meaning fully integrates the data sets and converts them into information. This study is carried out to evaluate the relationship between groundwater quality and surface water quality in Nambiyar river basin. The quality of ground water is the resultant of all the processes and reactions that act on the water from the moment it condensed in the atmosphere to the time it is discharged by a well or spring and varies from place to place and with the depth of the water table. The correlation coefficients obtained are tabulated in Table 6.24.

The study reveals the following relationship, There is no significant correlation between the pH of groundwater and pH of surface water quality with the other parameters, with EC of groundwater having a significant correlation (r = 0.6341), with HCO_3 of surface water, Cl of groundwater is having significant correlation (r = 0.6354) with HCO_3 of surface water, TDS of groundwater quality also having a significant correlation with HCO_3 of surface water (r = 0.6469), Na of groundwater is having significant correlation with Hardness of groundwater (r = 0.5687) and also with HCO_3 of surface water. NO_3 of groundwater is having a significant correlation with Hardness of surface water (r = 5616), Potassium of groundwater is having significant correlation with Hardness of surface water (r = 0.6906), Sulfate of groundwater is having nearly a significant correlation with HCO_3 of surface water (r = 0.5972).

Table 6.24 Correlation Coefficient between Various Groundwater and Surface Water Quality Parameter

	pH_gw	EC_gw	Hard_gw	Ca_gw	Mg_gw	HCO_3_gw	CO_3_gw	Cl_gw	TDS_gw	F_gw	Na_gw	NO_3_gw	K_gw	SO_4_gw
pH_sw	-0.2272	0.1834	0.2128	0.2048	0.3052	0.1027	-0.0973	0.1780	0.1921	-0.1063	0.1228	0.2058	0.1488	0.2057
EC _sw	-0.1176	0.1134	0.1432	0.1710	0.1920	-0.0831	-0.1518	0.1155	0.1338	-0.1007	0.0955	0.3896	0.0560	0.0622
Hard_sw	-0.1836	0.4504	0.2846	0.3832	0.3860	0.1742	-0.1233	0.4154	0.4847	0.1863	0.5687	0.5616	0.6906	0.5972
Ca_sw	-0.0327	-0.0011	0.0204	0.0519	0.0196	-0.1037	-0.1067	0.0100	0.0299	0.0144	0.0511	0.1677	0.1279	0.0535
Mg_sw	0.2619	-0.0059	-0.1140	-0.0427	-0.1574	0.1181	0.4123	-0.0208	-0.0028	-0.0116	0.1316	-0.2302	0.1124	0.1039
HCO_3_sw	-0.1946	0.6341	0.5852	0.6459	0.5099	0.2719	-0.1848	0.6354	0.6469	0.0090	0.6090	0.5417	0.3888	0.5549
CO_3_sw	-0.2534	0.0754	0.0856	0.0879	0.1921	-0.0210	-0.1359	0.0740	0.0931	-0.2302	0.0753	0.1476	0.1769	0.1780
Cl_sw	0.0165	-0.1264	-0.0848	-0.0670	-0.1158	-0.1488	-0.0011	-0.1076	-0.1087	-0.0289	-0.0898	-0.0475	-0.0161	-0.0958
TDS_sw	-0.0008	-0.0935	-0.0564	-0.0354	-0.0881	-0.1393	-0.0433	-0.0758	-0.0741	-0.0256	-0.0587	0.0030	0.0204	-0.0649
F_sw	0.0684	0.1970	0.1813	0.1498	0.3168	0.1112	0.0510	0.1628	0.2021	0.1125	0.1604	0.4005	0.0723	0.1827
Na_sw	0.0298	-0.0582	-0.0738	-0.0258	-0.1168	-0.0568	0.0508	-0.0578	-0.0514	-0.0272	-0.0195	-0.0496	-0.0080	-0.0076
NO_3_sw	0.1454	-0.0598	-0.1383	-0.0793	-0.1395	-0.2142	-0.1654	-0.0631	-0.0555	0.0671	-0.0133	0.1118	0.1623	0.0302
K_sw	-0.0427	-0.2596	-0.2212	-0.2164	-0.2478	-0.2063	-0.1641	-0.2502	-0.2617	0.0735	-0.2582	-0.1173	-0.0145	-0.2868
SO_4_sw	0.0394	-0.1757	-0.1037	-0.1312	-0.1152	-0.1838	-0.0893	-0.1481	-0.1640	-0.0625	-0.1723	-0.0828	-0.1186	-0.1866

CHAPTER 7

WATER QUALITY INDICES

7.1 GENERAL

WQI common with many other index systems, relate a group of water quality parameters to a common scale and combine them into a single number in accordance with the chosen method of computation. The desired use of WQI is to assess water quality trends for management / decision making purpose even though it is not meant for an absolute measure of the degree of pollution or the actual water quality.

7.2 WATER QUALITY INDEX BY SURFACE WATER SOURCES

To find the WQI of surface water quality in the basin, 13 physico-chemical and biological characteristics of water at 6 different surface sample point locations are shown in Figure 7.1, were taken into account. The parameters are pH, TDS, NO_3, BOD, COD, Total Alkalinity, Total Hardness, Ca, Mg, Cl, SO_4, and F. The five years' surface water quality data during the years 2002, 2003, 2004, 2005 and 2006 which are available with the TNPWD were used for the study to understand the surface water quality characteristic of the Nambiyar basin.

The water quality index was calculated considering 13 physico-chemical parameters using ICMR and ISI standards, by using the following formula.

$$WQI = \sum q_i w_i / \sum w_i \quad (7.1)$$

where,

WQI - Water Quality Index,

q_i - Quality rating of the n^{th} water quality parameter,

w_i - Unit weight factor

The quality rating ,

$$q_i = 100 (V_i - V_{10} / (S_i - V_{10}) \quad (7.2)$$

where,

V_i - Estimated value of the n^{th} parameter at a given sampling station,

S_i - WHO/ICMR/BSI Standard permissible value of n^{th} parameter,

V_{10} - Ideal value of the n^{th} parameter in pure water.

All the ideal values (V_{10}) are taken as zero for the drinking water except for Ph = 7.0 and DO = 14.6 mg/l. Based on the above WQI values, the water quality is rated as excellent, good, poor, very poor and unfit for human consumption shown in Table 7.1.

Table 7.1 WQI Categories

WQI	Description
0-30	Excellent
30-50	Good
50-60	Moderate
60-70	Poor
70-80	Very Poor
80-100	Unfit for drinking

Spatial distributions of surface water quality parameters were carried out through GIS and Geo-statistical techniques. WQI gives a clear picture about the usability of the water for different purposes. Water resources professionals generally communicate water quality status and trends in terms of the evaluation of individual water quality variables. While this technical language is readily understood within the water resources community, it does not readily translate itself to communities having profound influence on water resource policy: the general public and policy makers.

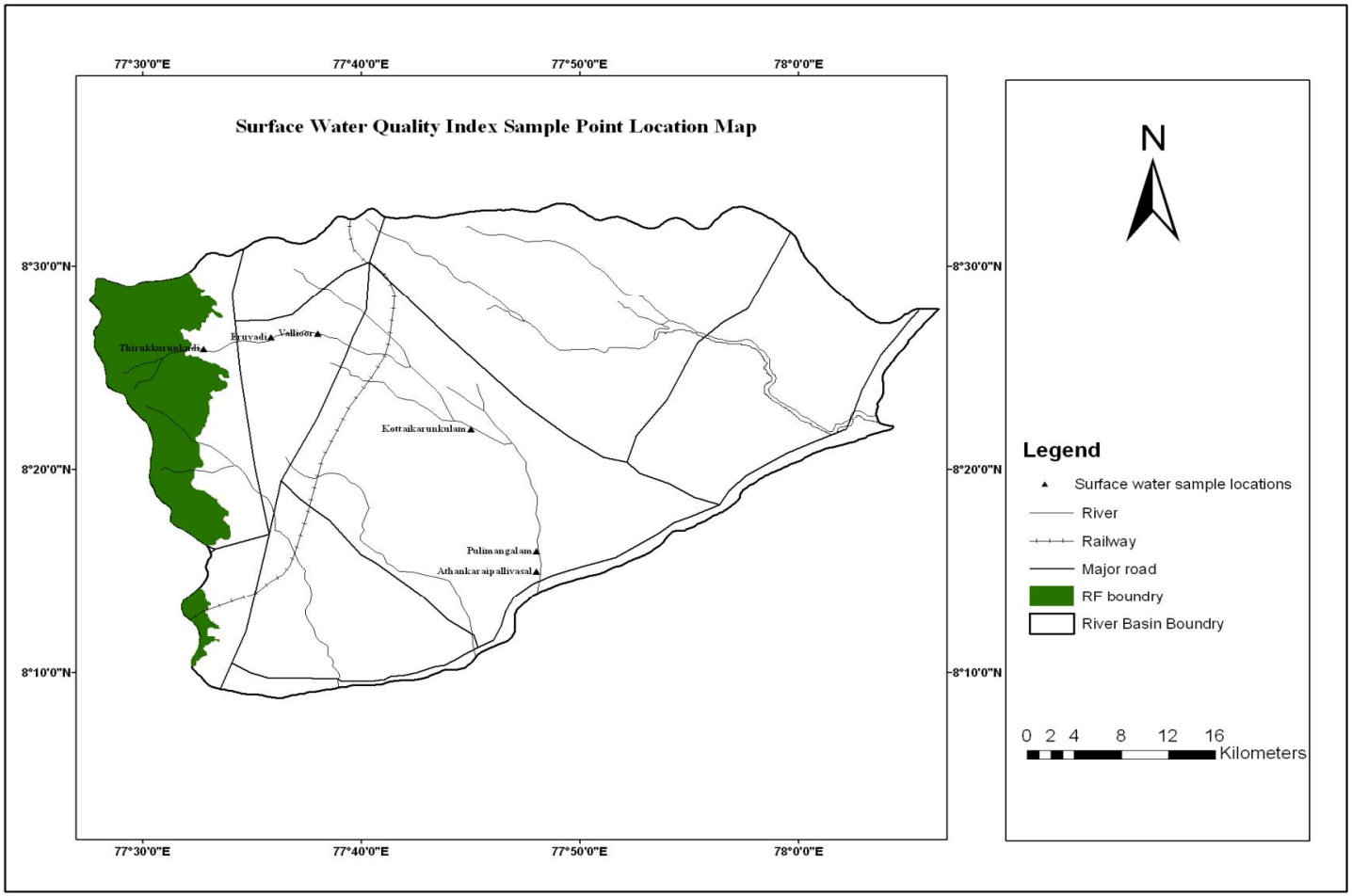


Figure 7.1 Sample Points Location Map of Surface Water Quality Index Study

This study reveals that the basin falls under the category of ‘moderate’ to ‘very poor’ and ‘predominantly very poor’ conditions with regard to the surface water.

The surface water quality index map has been created for the duration 2002 to 2006 are shown in Figure 7.2 to Figure 7.6. The maps reveal that the quality of water declines gradually from 2002 to 2006. But in the year 2004 the quality of surface water got a sudden peak compared with the other years. It may be the reason of poor rainfall over the catchment area of the basin or habitat changes of the basin area. Sample points are located in the middle of the basin; the values obtained in the North East, which are produced as a result of kriging interpolations, may not be taken into account for the secondary studies. For the primary level studies it can be used.

In the year 2002 as shown in Figure 7.2 the WQI values lie between 30 and 80 and fall in the categories of ‘excellent’ to ‘very poor’. In the year 2003 as shown in Figure 7.3, WQI lies between 54 and 77; it reveals that the water quality throughout the years falls in the ‘moderate’ categories. In the years 2004, 2005 and 2006 also the WQI values lie between 53 and 80, ‘moderate’ and ‘very poor ‘categories as shown in Figures 7.4, 7.5 and 7.6 respectively. From the result the overall characteristics of the basin show ‘good’ and ‘moderate’ quality in terms of WQI.

An accurate rational assessment of river water quality is needed for determining the extent of the usefulness of the river water. A ‘water quality index’ denoting the integrated effect of the various parameters that are relevant and significant to a particular use is proposed to express the water quality for different uses. WQI techniques have successfully demonstrated their capabilities in surface water quality mapping of Nambiyar River basin. Geo-statistical techniques create surfaces incorporating the statistical properties of the measured data. Because geo-statistics is based on statistics,

these techniques produce not only prediction surfaces but also error or uncertainty surfaces, giving an indication of how good the predictions are (Bilgehan 2008). A water quality index is a communication tool for transmitting information. The user of this information can range anywhere from being closely associated to being distantly connected to the resource. Accurate and timely information on the quality of water is necessary to shape sound public policy and to implement the water quality improvement programmes efficiently.

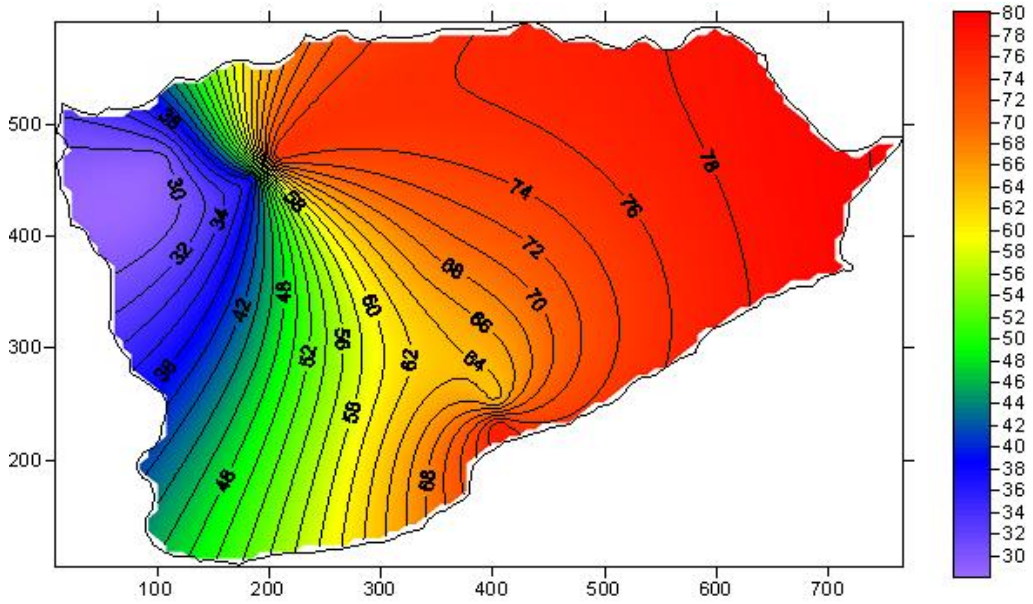


Figure 7.2 Surface Water Quality Index for the Year 2002

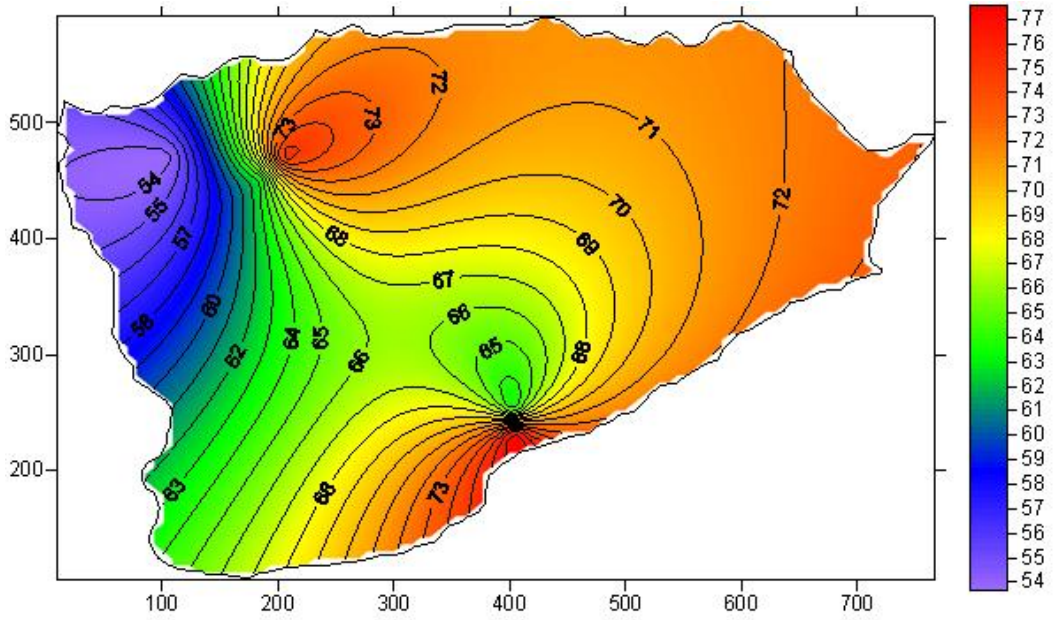


Figure 7.3 Surface Water Quality Index for the Year 2003

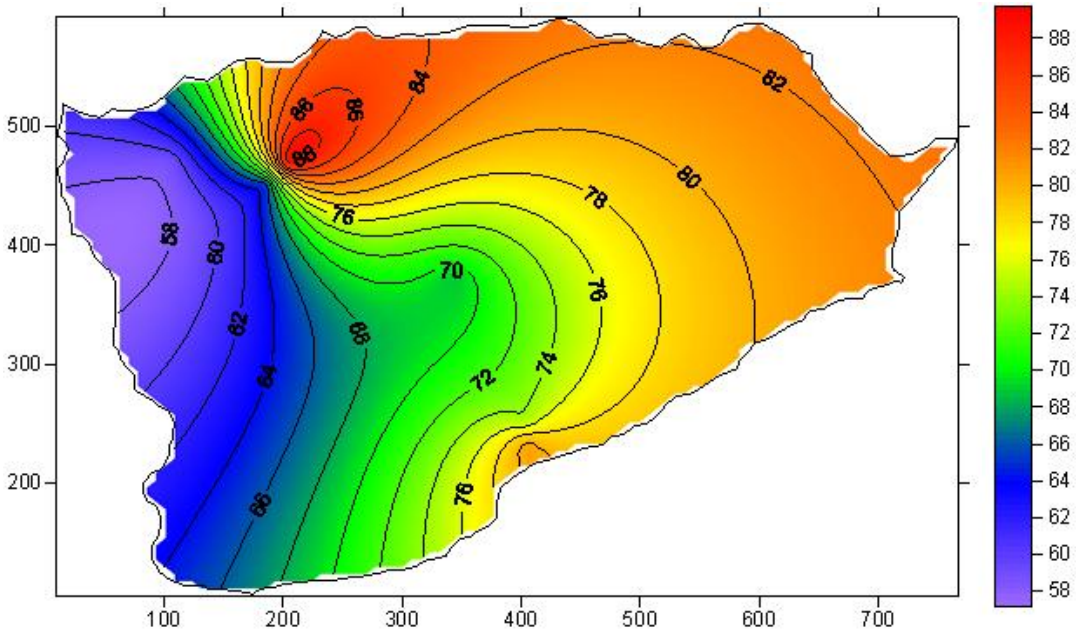


Figure 7.4 Surface Water Quality Index for the Year 2004

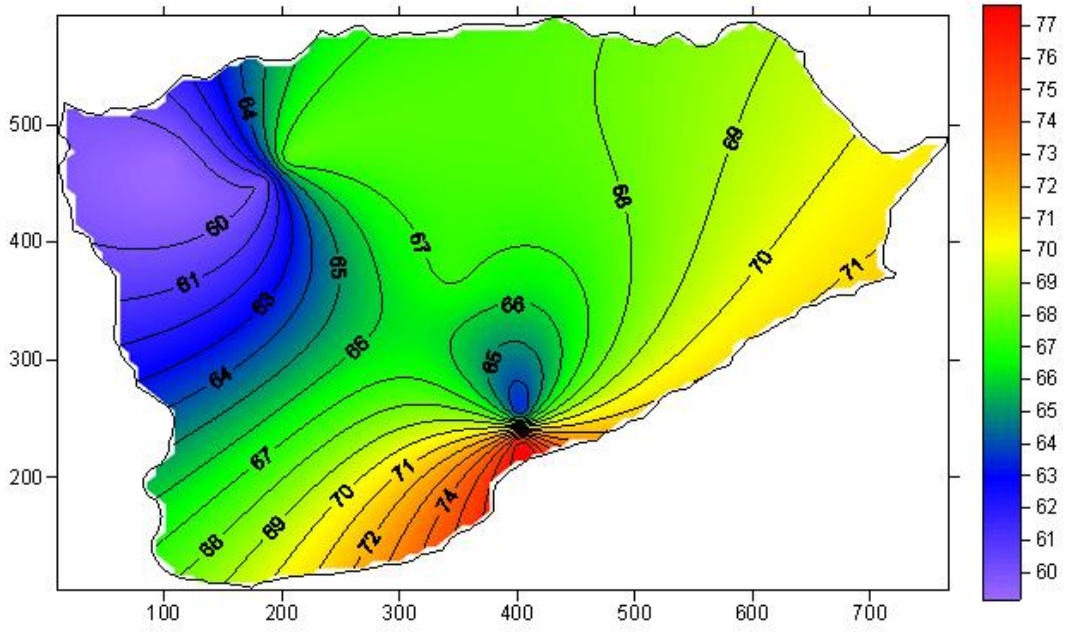


Figure 7.5 Surface Water Quality Index for the Year 2005

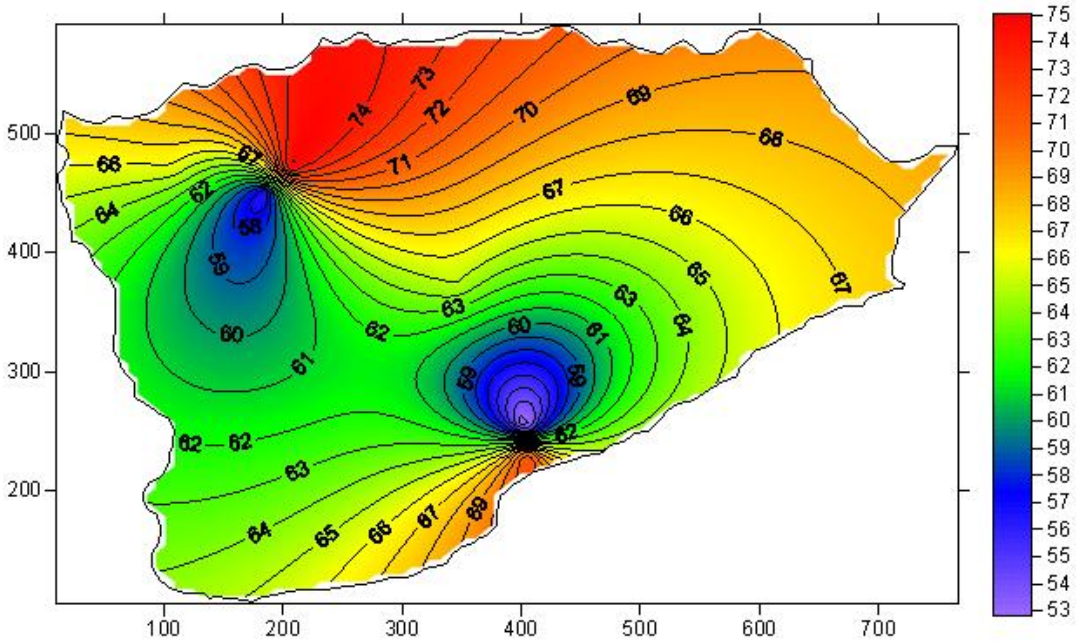


Figure 7.6 Surface Water Quality Index for the Year 2006

One of the most effective ways to communicate information on water quality trends to policy makers and the general public is with Indices. Water quality indices are useful for summarizing information in order to obtain a national perspective. On the basis of WQI Analysis of Nambiyar basin's water quality during 2002 to 2006, it has been revealed that the water of the basin is suitable for different purpose like irrigation and potable uses in the overall scenario.

7.3 WATER QUALITY INDEX BY GROUND WATER SOURCES

In this thesis an attempt has been made to identify the suitability of groundwater for human consumption based on computed Water Quality Index. Based on detailed well inventory survey in Nambiyar River basin, 32 representative groundwater wells (Created by Tamil Nadu Public Works Department (TNPWD), Government of Tamil Nadu, India, for regular monitoring of water quality) were selected for groundwater sampling program is shown in Figure 7.7 and the location ID details are given in Table 7.2. The groundwater sampling campaigns were carried out from the 32 representative wells during January 2009 and July 2009.

Field parameters such as electrical conductivity, pH, and temperature were measured in the field using portable meters. Water samples collected in the field were analyzed for chemical constituents, such as Calcium, Magnesium, Sodium, Potassium, Bicarbonate, Carbonate, and Chloride, in the laboratory using the standard methods as suggested by the American Public Health Association (1989, 1995).

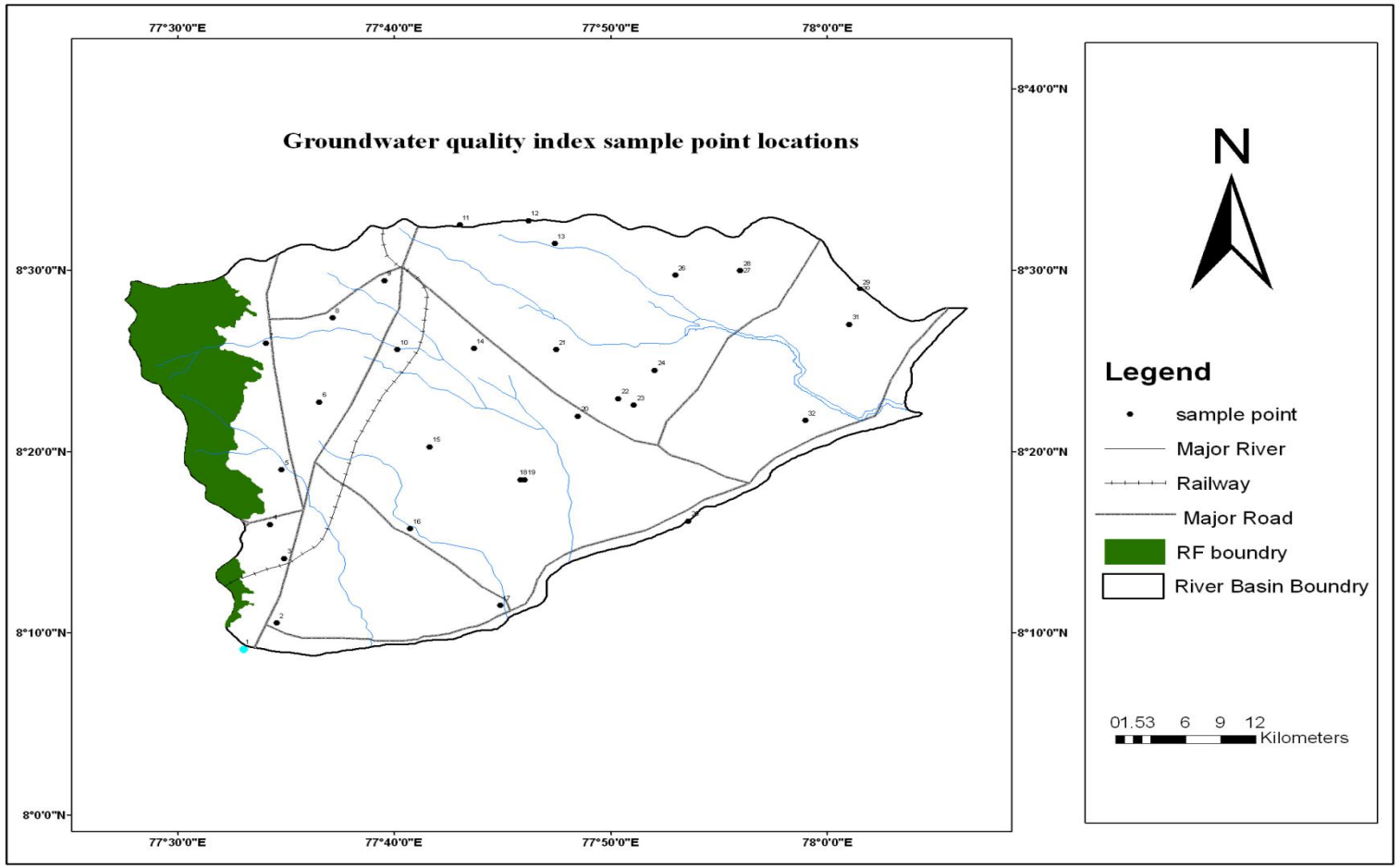


Figure 7.7 Sample Points Location Map for Water Quality Index study on Groundwater Quality

Table 7.2 Study area Locations ID Details

Station Name	ID	Station Name	ID
Bagavathipuram	1	Vijayapathi	17
Karunkulam	2	Kausturirangapuram	18
Soundaralingapuram	3	Kasturirangapuram (a)	19
Kavalkinar	4	Mannarpuram vilakku	20
Panagudi	5	Vadakku Vijayanarayanam	21
Valliyoor	6	Ittamozhipudur	22
Tirukkurungudi	7	Ittamozhi	23
Alangulam	8	Pudukulam	24
Nanguneri	9	Uvari	25
Tulukkarpatti	10	Karunkadal	26
Unnankulam	11	Anandapuram	27
Moolaikaraipatti	12	Ananda_puram	28
Munanjipatti	13	Tiruchendur	29
Parappadi	14	Sundarapuram	30
Samugarengapuram	15	Udankudi	31
Radhapuram	16	Padukkapathu	32

For computing ground WQI three steps are followed. In the first step, each of the 10 parameters has been assigned a weight (wi) according to its relative importance in the overall quality of water for drinking purposes are shown in Table 7.3. The parameters are pH, Total Hardness, Ca, Mg, HCO_3, Cl, TDS, F, NO_3, and SO_4.

The maximum weight of 5 has been assigned to the parameter nitrate, due to its major importance in water quality assessment. Magnesium

which is given the minimum weight of 2 as magnesium by itself may not be harmful.

In the second step, the relative weight (Wi) is computed using the following equation:

$$Wi = \frac{wi}{\sum_{i=1}^{n} wi} \tag{7.3}$$

where, Wi is the relative weight, wi is the weight of each parameter and 'n' is the number of parameters. Calculated relative weight (Wi) values of each parameter are given in Table 7.3.

Table 7.3 Relative Weight of Chemical Parameters

Chemical parameter	Indian Standard	Weight (wi)	Relative weight (Wi)
pH	6.5-8.5	4	0.1143
Hardness	300-600	3	0.0857
Ca	75-200	2	0.0571
Mg	30-100	2	0.0571
HCO_3	244-732	3	0.0857
Cl	250-1000	4	0.1143
TDS	500-2000	4	0.1143
F	1-1.5	4	0.1143
NO_3	45-100	5	0.1429
SO_4	200-400	4	0.1143
Total		35	1

In the third step, a quality rating scale (qi) for each parameter is assigned by dividing its concentration in each water sample by its respective standard according to the guidelines laid down in the BIS and the result multiplied by 100:

$$qi = (Ci / Si) \times 100 \quad (7.4)$$

SIi is the sub-index of i^{th} parameter; qi is the rating based on concentration of i^{th} parameter and 'n' is the number of parameters. The computed WQI values are classified into five types, "excellent water" to "water, unsuitable for drinking" shown in Table 7.4.

An accurate rational assessment of groundwater quality is needed for determining the extent of the usefulness of the groundwater sources. A 'water quality index' denoting the integrated effect of the various parameters that are relevant and significant to a particular use is proposed to express the water quality for different uses. WQI techniques have successfully demonstrated its capability in groundwater quality of Nambiyar River basin.

The groundwater quality index of the basin for the pre-monsoon and post-monsoon seasons has been presented in Figures. 7.8 and 7.9. Almost 50 percent of the samples lie between good and excellent. The high value of WQI at these stations has been found to be mainly from the higher values of calcium, TDS, and hardness in the groundwater. Less than 10 percentages of water samples are unfit for drinking purpose. In this part, the groundwater quality may improve due to inflow of freshwater of good quality during rainy season.

In this study, the computed pre-monsoon WQI values range from 19.44 to 550.65 and the post-monsoon values range from 26.51 to 316.97. Therefore they can be categorized into five types "excellent water" to "water

unsuitable for drinking". Table 7.4 shows the percentage of water samples that falls under different quality.

Table 7.4 Water Quality Classifications Based on WQI Value

WQI value	Water quality	% of water samples	
		Pre-monsoon	Post-monsoon
< 50	Excellent	22	19
50-100	Good	25	31
100-200	Poor	34	31
200-300	Very poor	13	16
> 300	Unsuitable	6	3

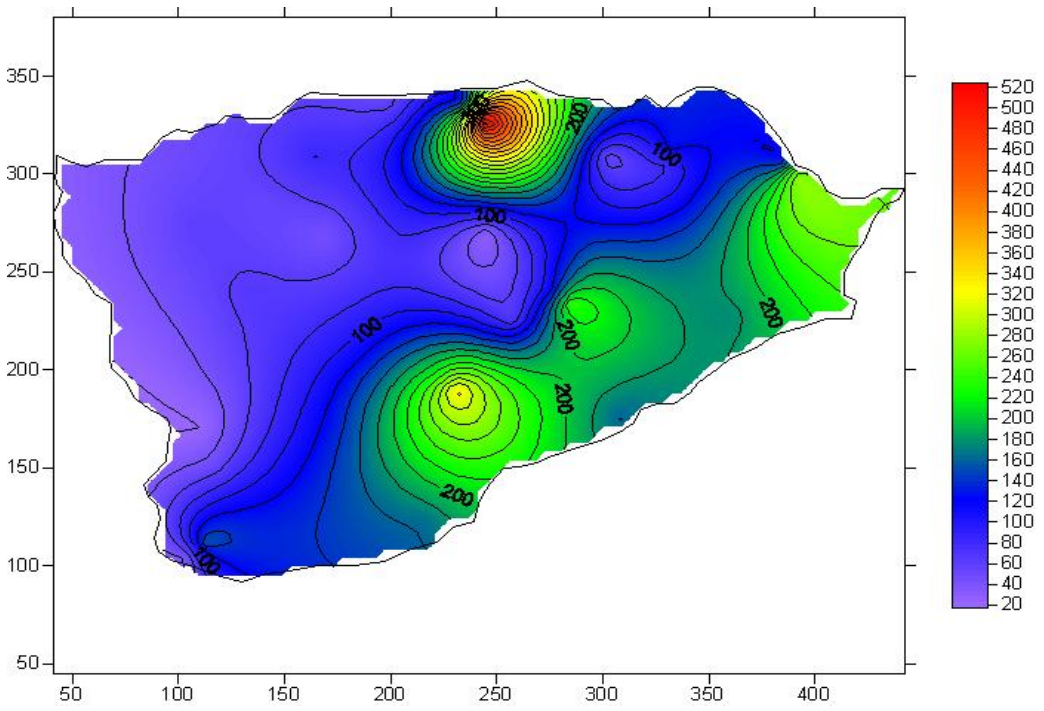


Figure 7.8 Ground Water Quality Index Map – Pre-Monsoon Period

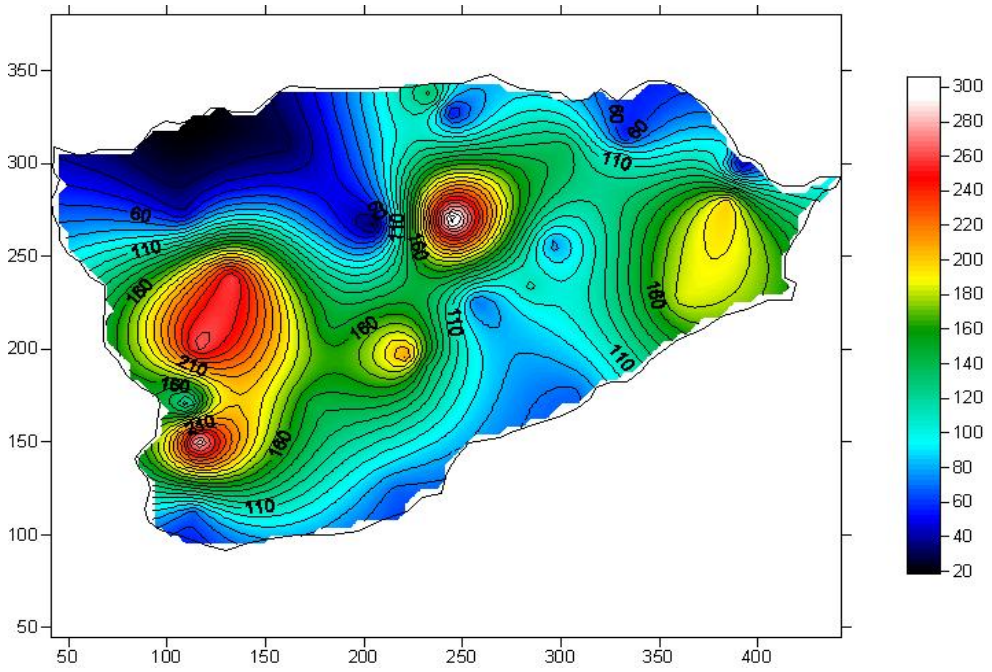


Figure 7 .9 Ground Water Quality Index Map - Post-Monsoon Period

CHAPTER 8

INTELLIGENT PREDICTIVE MODEL

8.1 GENERAL

The present chapter investigates the ability of Intelligent Predictive Model (IPM) to predict the water quality at Nambiyar River basin. Approaches based on IPMs are highly desirable in estimating the non-linear behavior of river water quality under historical and future scenarios. Due to the correlations and interactions between water quality parameters, it is interesting to investigate whether a domain-specific mechanism governing observed patterns exists to prove the predictability of these variables. The identification of such forecast models is particularly useful for ecologists and environmentalists, since they will be able to predict water pollution levels and take necessary precautionary measures in advance. Classical process-based modelling approaches can provide good estimations of water quality parameters, but they usually are too general to be applied directly without a lengthy data calibration process (Sundarambal et al 2008). The neural network model has been integreated as a thematic layer in a GIS allowing an efficient management and update of the records used to develop the models.

The most popular predictive model usually applied to non-linear environmental relationships is the ANN (Zhang and Stanley 1997). Hafizan et al (2004) showed that the ANN model gives a better performance compared to the Auto Regressive Integrated Moving Average (ARIMA) model in forecasting DO. Applications of ANN in the field of water

engineering, ecological sciences, and environmental sciences have been reported since the beginning of the 1990s. Many authors have carried out comparison studies between statistical techniques and neural networks. However, few of the ANN models have tried to visually integrate GIS with the feed-forward Back Propagation Network (BPN), a type of ANN, to create a GIS-BPN-based, visual river water quality model. An attempt has been made in this thesis to predict the groundwater quality in Nambiyar River basin.

8.2 DATA COLLECTION AND ANALYSIS

From the 32 representative groundwater wells (created by Tamil Nadu Public Works Department (TNPWD), Government of Tamil Nadu, for regular monitoring of water quality) were selected for groundwater sampling program. The sample location is shown in Figure 8.1, and the respective location ID is given in Table 8.1. To understand the long-term variation in groundwater quality and to run ANN, the groundwater sampling campaigns were carried out during January 2009 and July 2009. This long-term water quality data are considered as Secondary Data (SD). Field parameters such as electrical conductivity, pH, and temperature were measured in the field using portable meters. Water samples collected in the field were analyzed for chemical constituents, such as Calcium, Magnesium, Sodium, Potassium, Bicarbonate, Carbonate, and Chloride, in the laboratory using the standard methods suggested by the American Public Health Association (1989, 1995).

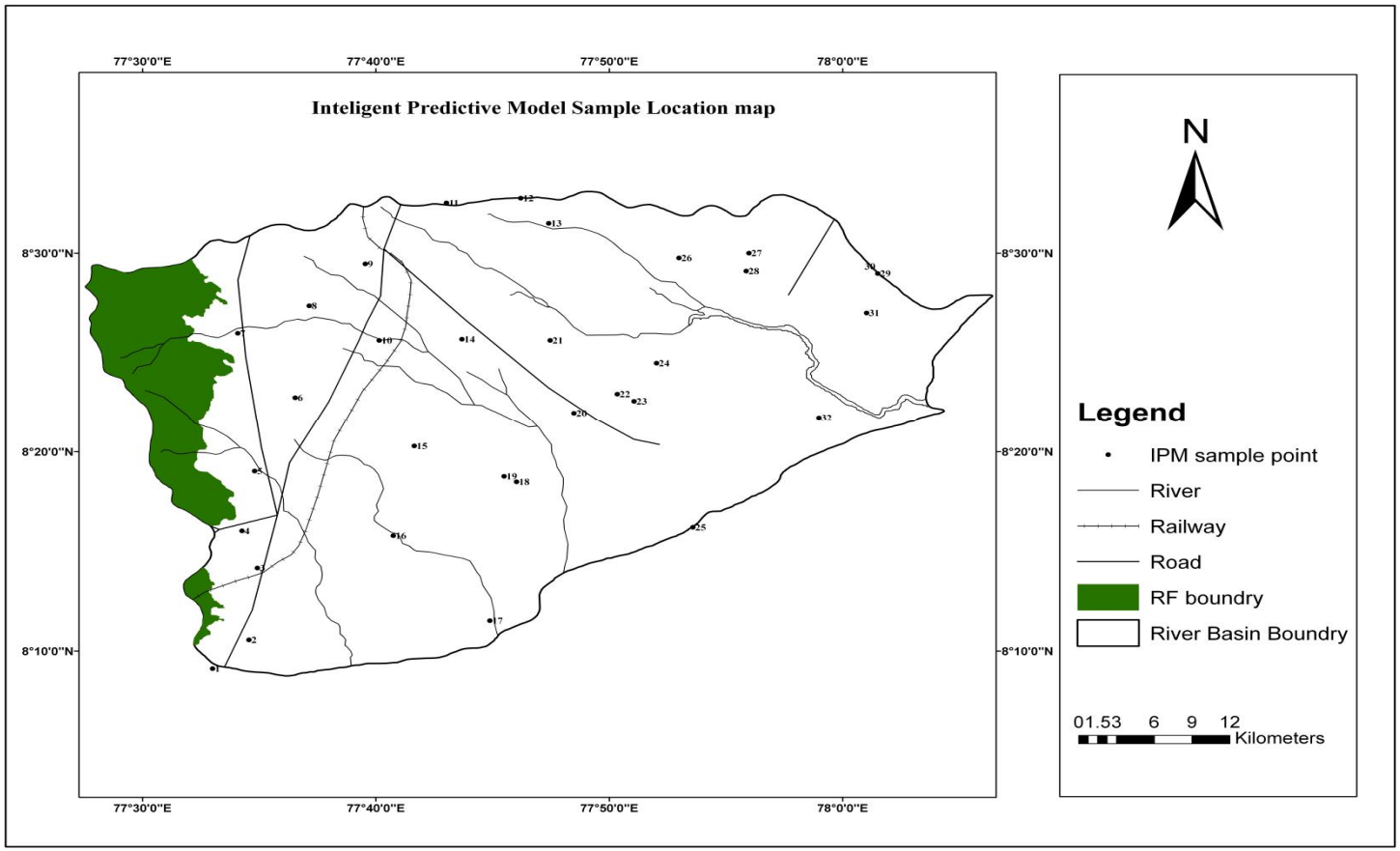


Figure 8.1 Intelligent Predictive Model Sample Points Location Map

Table 8.1 IPM sample point locations ID Details

Station Name	ID	Station Name	ID
Bagavathipuram	1	Vijayapathi	17
Karunkulam	2	Kausturirangapuram	18
Soundaralingapuram	3	Kasturirangapuram (a)	19
Kavalkinar	4	Mannarpuram vilakku	20
Panagudi	5	Vadakku Vijayanarayanam	21
Valliyoor	6	Ittamozhipudur	22
Tirukkurungudi	7	Ittamozhi	23
Alangulam	8	Pudukulam	24
Nanguneri	9	Uvari	25
Tulukkarpatti	10	Karunkadal	26
Unnankulam	11	Anandapuram	27
Moolaikaraipatti	12	Ananda_puram	28
Munanjipatti	13	Tiruchendur	29
Parappadi	14	Sundarapuram	30
Samugarengapuram	15	Udankudi	31
Radhapuram	16	Padukkapathu	32

8.3 NEURAL NETWORK MODEL

A neural network consists of a set of interconnected individual neurons organized into several layers; the first layer being the input layer, which produces the network output. The flow diagram is shown in Figure 8.2. Numerical data moves from connection to each unit whereupon it is processed. Processing takes place locally at each unit and between connections in a parallel fashion.

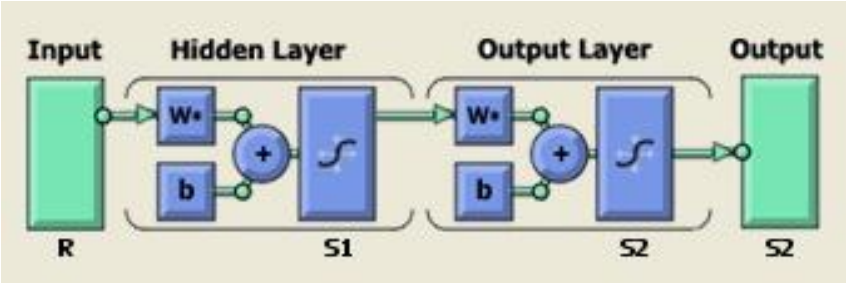


Figure 8.2 Neural Network Flow Diagram

In this thesis, the study of ANN modelling to predict TDS, Cl, and Hardness in Nambiyar River basin is presented.

8.4 GIS INTEGRATION

ANN when coupled with GIS can be used for many applications for the purpose of improved decision-making. Recent use of GIS in modelling can simplify the process, add confidence in the accuracy of modelled watershed conditions, and improve the efficiency of the modelling process (Liao and Tim 1997, Basnyat et al 2000, Jensen 2000, He et al 2001).

GIS information can become increasingly more valuable for decision making when coupled with ANN. When linked with GIS, ANN can be useful for evaluating, monitoring and decision making. Spatial model with GIS is a proven method that has been well documented in many deterministic

model studies (Solaimani et al 2009). Visual results of model can reflect effectively spatially-varied complexities in water systems.

The databases of the model contain two types of data: ‘spatial data’ and ‘attribute data’. The spatial data include Arc View shape files mainly representing the 32 measured points of the Nambiyar River basin. The attribute data describe the features of the places (32 sample points), that is, concentration of TDS, EC, Cl, Mg and Hardness. The visual geographical distributions of TDS Model, Cl Model, and Hardness model are presented in Figures 8.3, 8.4, and 8.5 respectively.

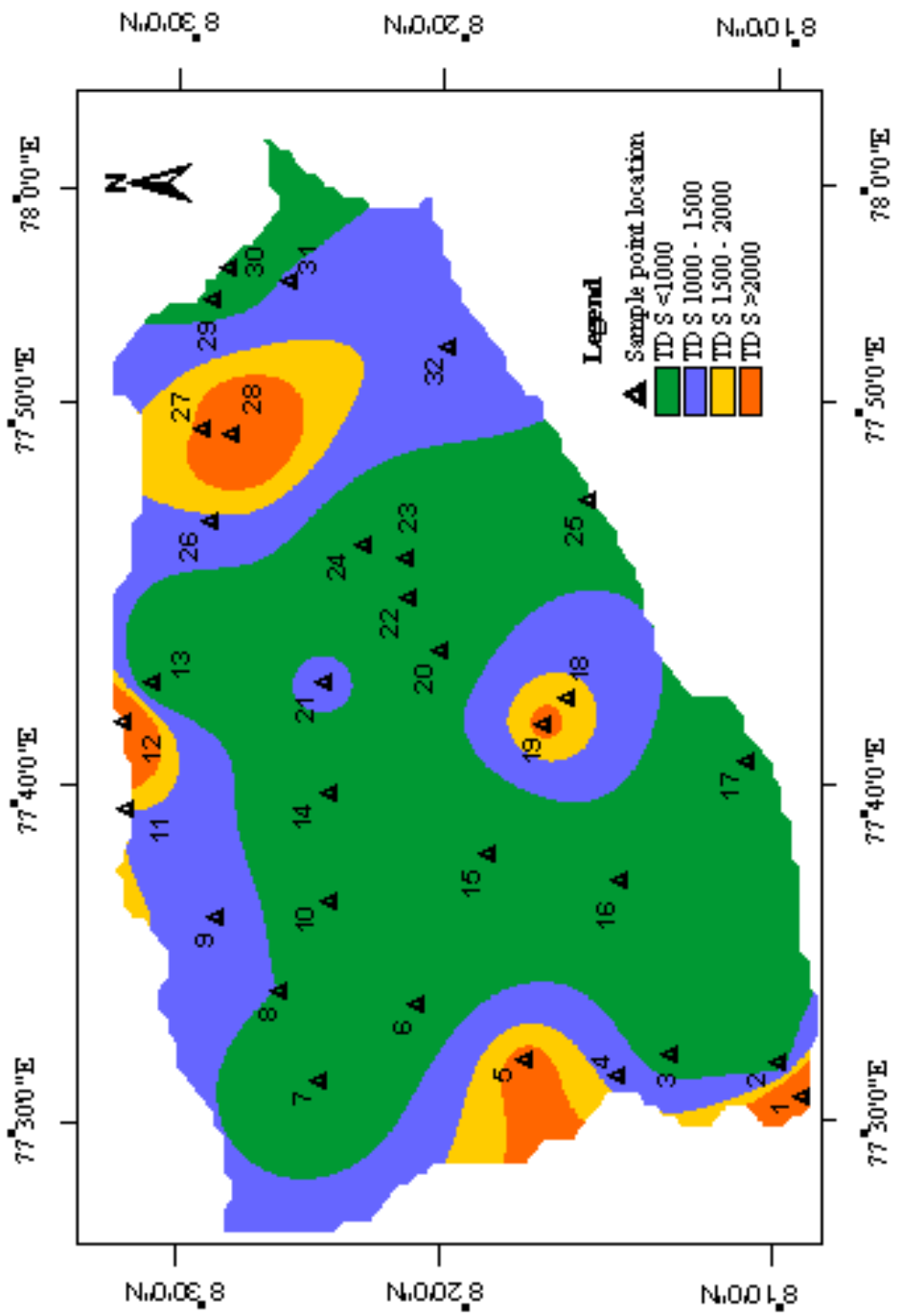


Figure 8.3 TDS Model Output Map of the Study Area

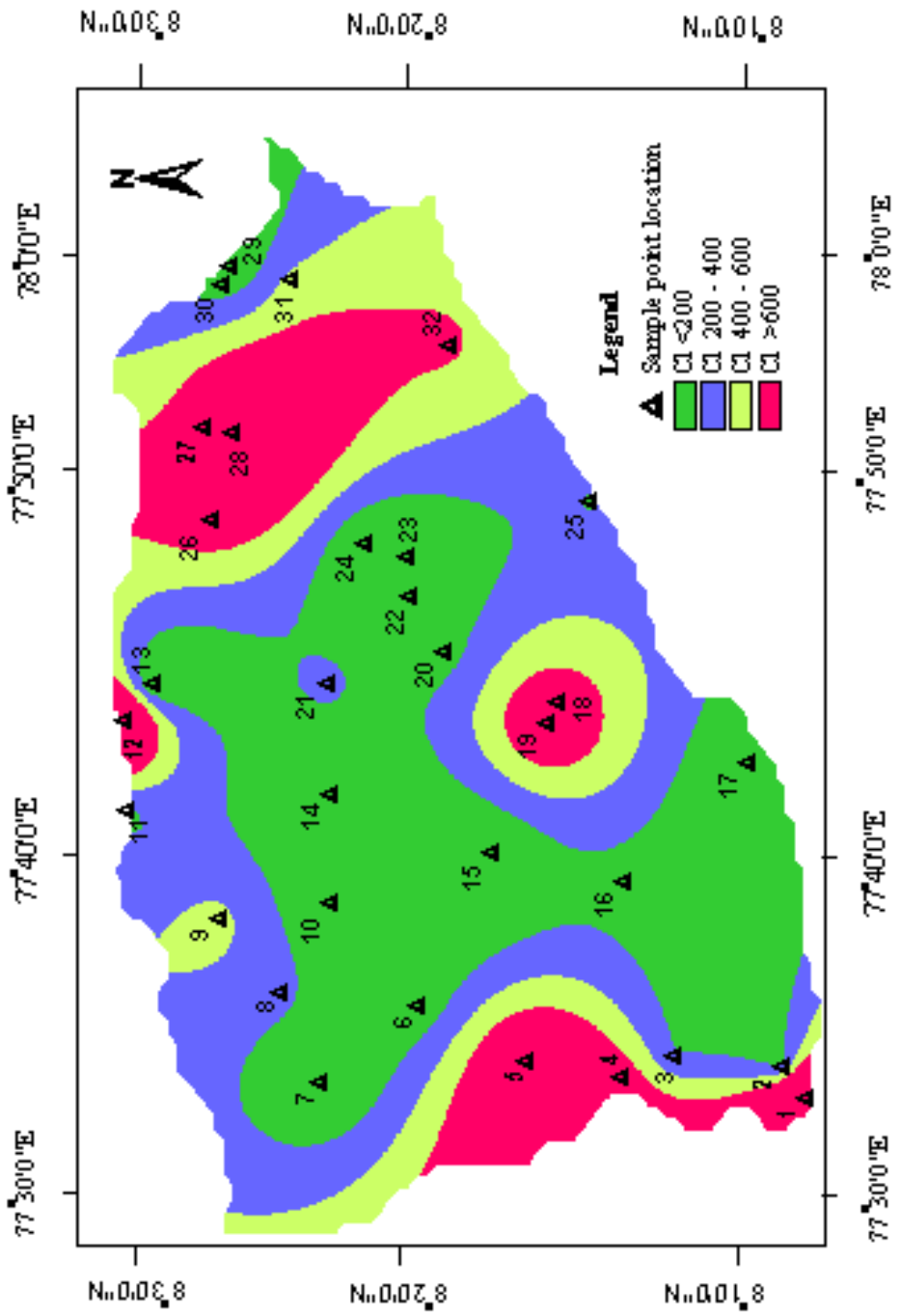


Figure 8.4 Cl Model Output Map of the Study Area

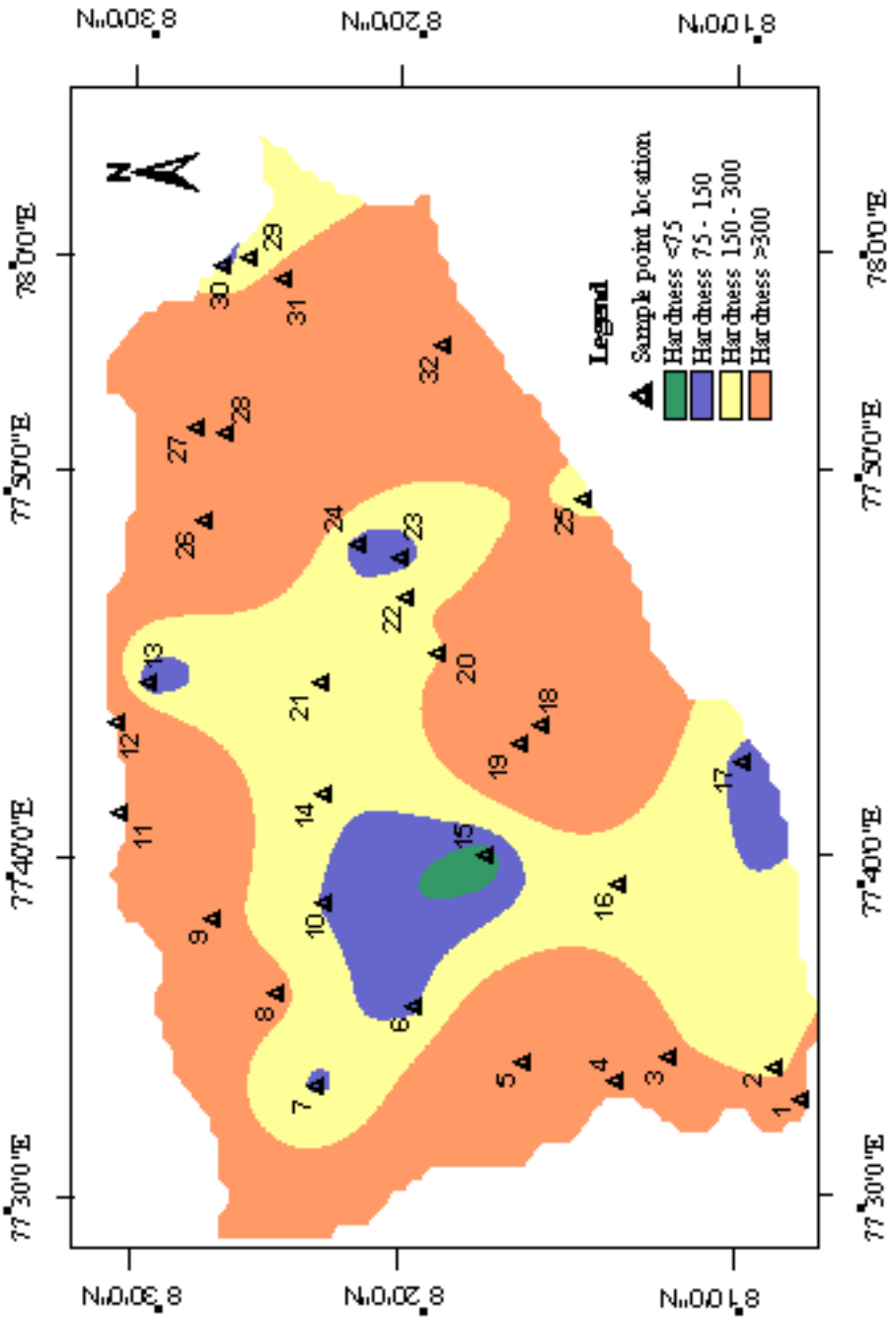


Figure 8.5 Hardness Model Output Map of the Study Area

Understanding the quality of groundwater is as important as its quantity, because it is the main factor determining the suitability for drinking, domestic, agricultural, and industrial purposes (Phiri et al 2005, Chimwanza et al 2006, Jain et al 2006, Alam et al 2007). The summary of statistical data analysis result is shown in Table 8.2. The pH value ranged from 6.9 to 9.3, indicating that the study area water is alkaline in nature. Some well waters have higher concentration of pH due to weathering of plagioclase feldspar by dissolved atmospheric carbon dioxide that will release sodium and calcium which progressively increases the pH and alkalinity. This kind of result is observed by Njitchoua et al (1997), Chenini and Khemiri (2009), Pejman et al (2009) Ram Kumar et al. (2010), and Mohiuddin et al (2010). The Electrical Conductivity ranges from78 µS/cm to 9,800 µS/cm. The higher values are generally noticed in the southeast sites of the study area. TDS value range from 70 mg/l to 1,700 mg/l. Higher concentration of TDS is likely due to mixing of groundwater with seawater, which has a local and limited effect on a few wells in the coastal area. The same kind of result is observed by Aiuppa et al (2000) and Ramkumar et al (2010).

8.5 CORRELATION OF PHYSICOCHEMICAL PARAMETERS

One of the objectives of the work reported in this thesis is to reduce the number of parameters needed to carry out water quality prediction without loss of information. To meet this objective, correlation analysis was employed to investigate the relationship of each water quality parameter to the dependent variables. Correlation coefficient is a commonly used measure to establish the relationship between two variables. It is simply a measure to exhibit how well one variable predicts the other. The correlation matrices for 14 variables were prepared for the study area and presented in Table 8.3. The result shows good positive correlation between EC with TDS and Cl, Hardness with Mg. Significant correlations also exist between the pairs Na-EC, Mg-EC, Hardness-EC, Na-TDS, Ca-TDS, Mg-TDS, Cl-Na, and Cl-Mg.

Table 8.2 Summary of Water Quality Parameters

Parameter		EC	pH	TDS	Hardness	Ca	Mg	Na	K	HCO_3	CO_3	Cl	SO_4	NO_3	F
Unit	**-**	**µS/cm**	**-**	**ppm**											
Primary (Jan 2009 - July 2009)	**Minimum**	83	6.8	70	120	10	2	4	2	37	6	7	27.8	0.44	0.16
	Maximum	9,140	9.5	1,700	1,060	923	578	976	97	568	85	2,765	125	45	1.20
	Mean	1,947	8.1	876	568	136	87	142	14.7	127	15	378	72.6	16.7	0.81
	Median	1,343	8.1	912	673	68	94	117	11.3	198	17	198	71.3	17	0.70
	Standard Deviation	1,567	0.416	564	395	243	96.3	146	13.67	47.86	8.7	578	21.3	14.53	0.23
Secondary (1995 - 2008)	**Minimum**	78	7.0	150	70	6	3	4	1	32	5	7.9	22	0	0.12
	Maximum	9,800	9.7	1,500	978	780	542	780	248	432	73	2,561	117	38	1.7
	Mean	1,765	8.6	765	289	85.3	72.4	147	23.4	256	8	432	70	12	0.62
	Median	1,456	8.6	780	321	63	47.6	112	10	273	5	275	65	9	0.70
	Standard Deviation	1,245	0.31	976	278	89.6	86	143	37.8	32.7	7.3	342	19	13	0.67
Total	**Minimum**	78	6.9	70	70	6	2	4	1	32	5	7	22	0	0.12
	Maximum	9,800	9.3	1,700	1,060	923	578	976	248	568	85	2,765	125	45	1.20
	Mean	1,546	8.7	769	550	112	75.4	137	20.78	193	22	375	66	13	0.73
	Median	1,445	8.7	765	376	89	63	112	10	124	34	264	60	12	0.63
	Standard Deviation	1,376	0.4	674	258	103	72	143	35.7	45.9	22	3.7	43	16	0.35

Table 8.3 Correlation Matrix of Physio-chemical parameters

	EC	**pH**	**TDS**	**Na**	**K**	**Ca**	**Mg**
EC	1.0000						
pH	0.1476	1.0000					
TDS	0.9309	-0.1198	1.0000				
Na	0.8338	-0.0392	0.8987	1.0000			
K	0.3917	0.0031	0.4591	0.3522	1.0000		
Ca	0.7743	-0.1799	0.8227	0.5768	0.2789	1.0000	
Mg	0.8197	-0.1277	0.8691	0.6496	0.4045	0.6986	1.0000
Cl	0.9539	-0.1376	0.9109	0.8083	0.3551	0.7672	0.8260
HCO_3	0.2488	-0.0259	0.3521	0.3992	0.2451	0.2288	0.2378
CO_3	0.0729	0.5907	-0.0341	0.0293	0.0947	-0.1091	-0.0450
SO_4	0.6990	-0.0983	0.7641	0.6966	0.3533	0.5698	0.6471
NO_3	0.4358	-0.1647	0.3871	0.2506	0.3042	0.3433	0.3595
F	0.0331	-0.0428	0.0693	0.0842	-0.0044	0.0424	0.0638
Hardness	0.8661	-0.1633	0.9190	0.6676	0.3778	0.9043	0.9369
	Cl	**HCO_3**	**CO_3**	**SO_4**	**NO_3**	**F**	**Hardness**
Cl	1.0000						
HCO_3	0.1417	1.0000					
CO_3	-0.0853	0.1088	1.0000				
SO_4	0.5960	0.2572	-0.0318	1.0000			
NO_3	0.3761	0.0524	-0.1076	0.3302	1.0000		
F	0.0215	0.1193	-0.0657	0.0639	0.0252	1.0000	
Hardness	0.8669	0.2522	-0.0796	0.6620	0.3807	0.0589	1.0000

8.6 REGRESSION

Liner Regression Model was applied as well in this work to justify the relationship between the water quality parameters, viz. relating TDS with EC, Cl with EC and Hardness with Mg, using the training data set and also to compare the ANN model capabilities. The equations obtained were then tested with 642 test data to evaluate the predictability of the developed empirical relations. It is observed that the relation Y = 0.6119X - 42.641 with standard error of 0.00560 as shown in Figure 8.6 can be used to estimate TDS, while the relation Y = 0.2631X - 95.292 with standard error of 0.01248 shown in Figure 8.7 can be used to estimate Cl, and Y = 6.0098X + 141.84 with standard error of 0.553901 shown in Figure 8.8. The regression model results are then compared with the Neural Network Model results.

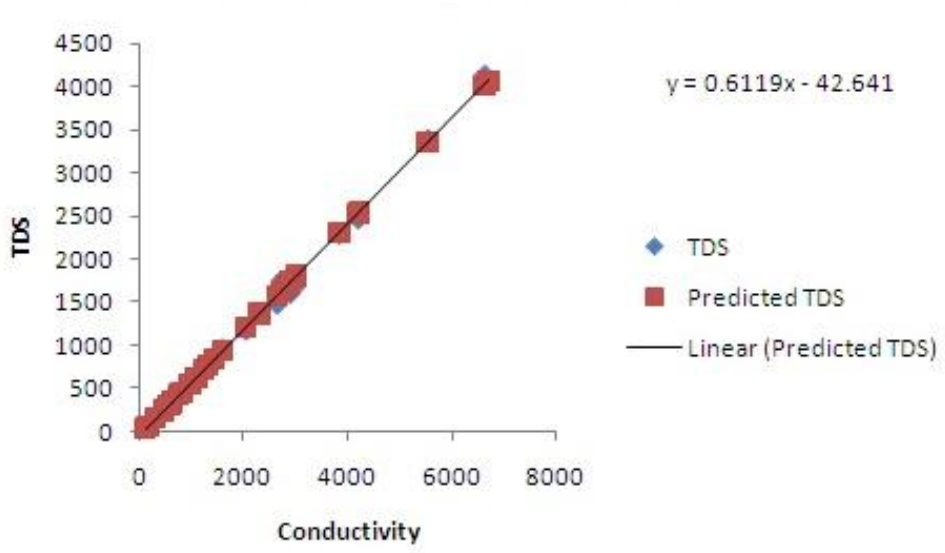


Figure 8.6 TDS Regression Model Output

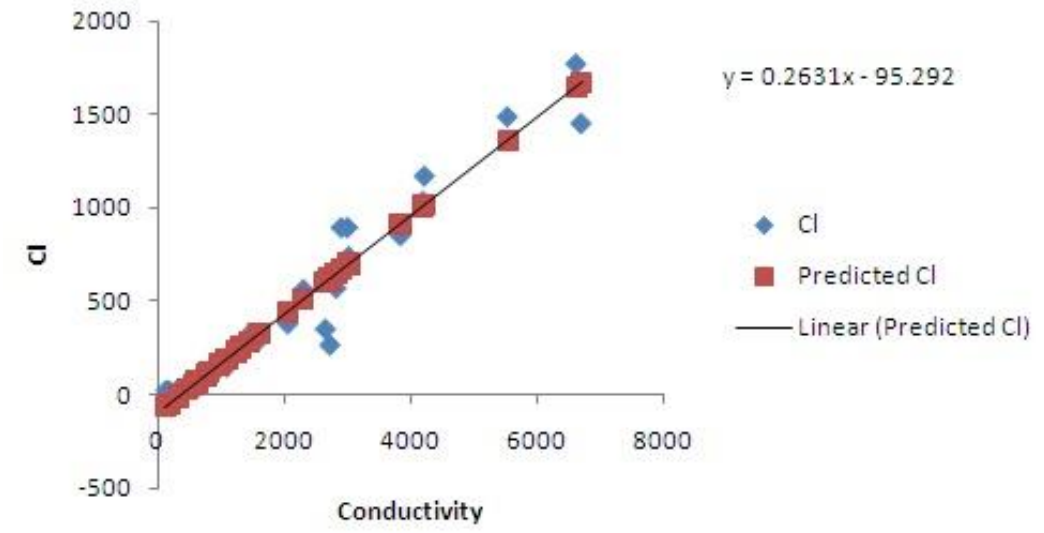


Figure 8.7 Chloride Regression Model Output

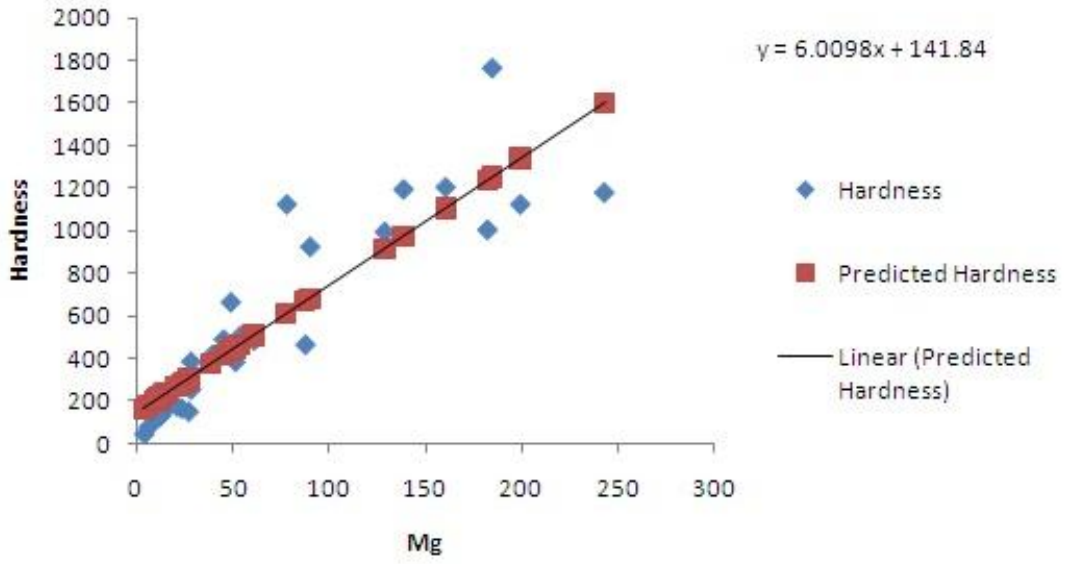


Figure 8.8 Hardness Regression Model Output

8.7 NEURAL NETWORK MODEL

ANN models can work even with not-so-correlated predictors; all the values can be considered on the same foot while constructing single-hidden-layer ANN models (Bandyopadhyay and Chattopadhyay 2007). Based

on Correlation Analysis, only four variables (TDS, Cl, Mg, and Hardness) meet the requirement as good predictors for the IPM generation using ANN for this basin. To justify the best predictor combination of ANN model, the data available with Tamil Nadu Public Works Department (from 1995 to 2008) were used as training and validation data set. To test the data, samples were collected and analyzed in the laboratory (2009) and used as the testing data set. In the present work feed-forward BPN algorithm was used by the software Mat lab Neural Network tool.

8.7.1 Data Partition

The data in neural networks are categorized into three sets: training or learning sets, validation and test or over-fitting test set. A total of 3210 data samples were divided into a training sets consisting of 1926 samples (60% of the total), (1995 to 2008) 642 samples (20% of the total) (1995 to 2008) were used for validation and the remaining 642 samples (20% of the total samples) (2009) were used for testing.

The results show that the proposed ANN-GIS based IPM has great potential to simulate and predict the TDS, Cl and Hardness with acceptable accuracies of Mean Square Error (MSE): TDS_{MSE} = $1.58319E^{-4}$; Cl_{MSE} = $3.23229666E^{-4}$; $HARDNESS_{MSE}$ = $1.78177E^{-4}$. The results are shown in Figs. 8.5 to 8.7. On close observation of graphs of these two models, it is evident that most errors for regression model are little more than error generated by the ANN Model (refer Figs. 8.6, 8.7, and 8 .8 with Figs. 8.9, 8.10 and 8.11 respectively).

8.7.2 Total Dissolved Solids Model

The ANN-based Intelligent Predictive Models were developed to simulate and predict the TDS at Nambiyar River basin. It used an ANN-

architecture BPN algorithm. After several trials 750 hidden layer combinations yield the best result. TDS are more important measurements to be considered when examining water quality.

TDS comprise inorganic salts and small amounts of organic matter that are dissolved in water. It determines the suitability of water for agricultural uses, since TDS are not easily measured except under controlled conditions in reputable laboratories.

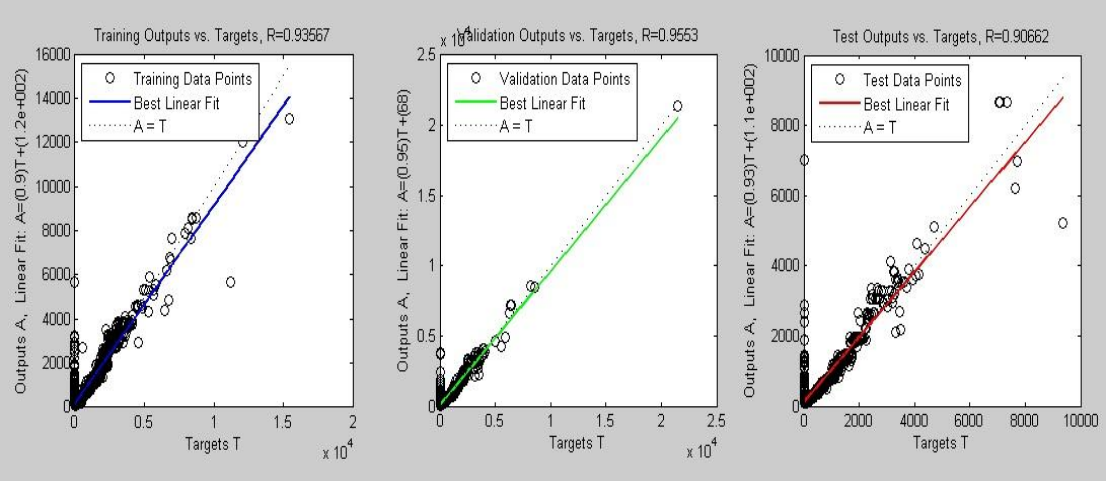


Figure 8.9 ANN Prediction Model for TDS

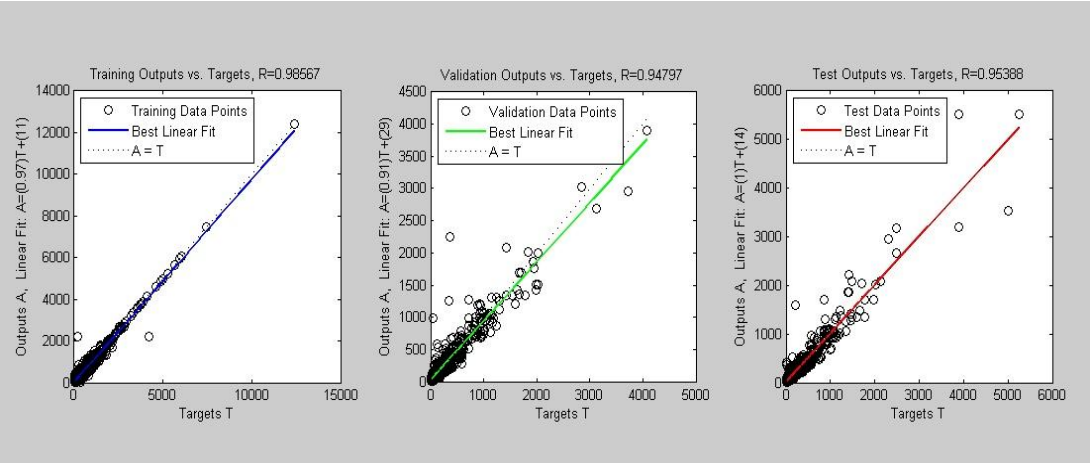


Figure 8.10 ANN Prediction Model for Cl

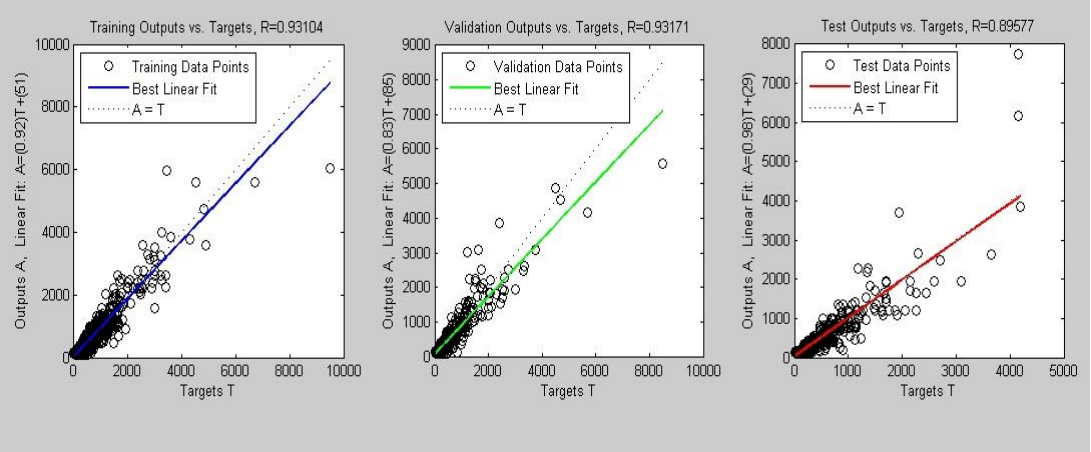


Figure 8.11 ANN Prediction Model for Hardness

8.7.3 Chloride Model

The ANN-based IPM has been developed to simulate and predict the Cl at Nambiyar River basin. It used an ANN- architecture BPN algorithm. After several trials 550 hidden layer combinations yielded the best result. Chloride is associated with major quality parameters. Significant changes in chloride could be an indicator that a discharge or some other source of pollution has entered a stream. The ANN model was used in this paper to simulate and predict the Cl with EC as the only input.

8.7.4 Hardness Model

The ANN-based IPM has been developed to simulate and predict the Hardness at Nambiyar River basin. It used an ANN-architecture BPN algorithm. After several trails 850 hidden layer combinations yielded the best result. Hardness is associated with major quality parameters.

8.7.5 Model Performance Evaluation

To reach the suitable network architecture, several trials for each group have been conducted until the suitable learning rate, number of hidden layers and numbers of neurons per each hidden layer were reached. The

suitable architecture is the one which produced the minimal error term in both training and testing data. The back propagation algorithm minimizes the Mean Square Error (MSE) between the observed and the predicted output in the output layer. The performance of each network model is evaluated by computing the mean absolute percentage error (MAPE) and MSE. The structure that resulted in minimum errors was the one selected. Since the water parameters were accurately monitored over the 11 years (1997 – 2008), the performance of the proposed ANN-based Intelligent Predictive Model can be examined and evaluated. The performances of the models are evaluated using the laboratory result (2009) from the same 32 monitoring points. In addition, visual analysis for the prediction data was carried out using ArcGIS.

ANN captures the embedded spatial and unsteady behaviour in the investigated problem, using its architecture and non-linearity nature, compared with the other classical modelling techniques. ANNs when coupled with GIS can be used for many applications for the purpose of improved decision-making. GIS implemented model can be improved easily in resolution and realism if newer research results, more accurate input data or better hard- and software are available (Sivertun and Lars 2003). Neural networks are being used in a wide variety of applications as an important decision making tool. This thesis suggests the use of ANN-based water quality parameters prediction model for Nambiyar River basin. Three main parameters have been studied, viz. TDS, Cl and Hardness. In fact, the proposed ANN-based GIS coupled IPM requires no prior knowledge of the natural physical processes of these water quality parameters. Despite the highly stochastic nature of the proposed water quality parameters, the proposed models are capable of mimicking the water quality parameters accurately with relatively small prediction error. The ANN-based GIS coupled IPM exhibits robustness and reliable performance in predicting the TDS, Chloride and Hardness with EC and Magnesium as the input parameters.

CHAPTER 9

CONCLUSION

9.1 GENERAL

In this chapter, the findings of the research works carried out in this thesis are summarised and the conclusions emerging from the study presented. The scope for further research in this direction is also outlined.

9.2 SUMMARY AND CONCLUSIONS

The major conclusions derived from the hydro-geochemical studies, water quality trends and water quality prediction modelling of Nambiyar River basin, Tamil Nadu are outlined below.

1. The interpretation of hydro-geochemical analysis reveals that the groundwater in Nambiyar River basin is fresh to brackish and alkaline in nature, which is good for drinking and agricultural purpose. The major cations (Ca, Na, Mg and K) and major anions (Cl, HCO_3, SO_4 and CO_3) of the study area are well within the permissible limits for the entire area. In major places, total hardness is generally within the limits in the groundwater, which makes the groundwater of the study area suitable for drinking. The concentration of Fluoride is within the permissible limits for drinking in the entire basin during the study period.

2. In general the quality of groundwater in Nambiyar Basin is good and moderate in most of the observations wells. Saline pockets are observed in certain areas like Vadakku Valliyur, Vijayanarayanam, Padukkapathu, Anandapuram and Udangudi. The main reason for the presence of larger amount of dissolved solids may be due to geological formation or seepage from fertilizers or local contamination. This may cause high salinity.

3. Generally the pH of the water has a small variation due to buffering action of water with Carbon-di-oxide. Regarding the Nambiyar basin the pH value range lies within the permissible limit except in few places. The higher pH observed in this basin is found to be above 8.5 in Moolakaraipatti, Sundarapuram and Itamozhipudur. This may be due of to Calcium carbonate bearing rock formations.

4. The Chloride concentrations in all the wells of this basin are found to be within the maximum limit except in few wells. When the salt concentration is increased, it is difficult for plants to extract water. Chlorides are more toxic to some plants.

5. The quality of ground water depends on the different types of rocks encountered. Major portion of the Nambiyar basin is covered with hard rock and the tail end of this basin with sedimentary rock formation. Hardness is due to presence of Calcium, Magnesium, Bicarbonate and Chloride ions.

6. The concentrations of Nitrate in most of the wells are within the maximum acceptable limit except in some places like

Valliyoor, Udangudi, Vijayanarayanam and Karunkadal. The increased concentration of Nitrate may be due to excessive application of nitrogen fertilizers or decay of plants and animals' residue or disposal of industrial wastewater or sewage or by increased cultivation of leguminous plants. The toxicity of Nitrate leads to cardiovascular effects at higher dose level and Methomoglobinemia at lower dosage limits.

7. The concentration of Fluoride is found to be within the permissible limit in most of the areas. When the intake of Fluoride is above the permissible limit, it leads to skeletal and dental fluorosis. The Fluoride contamination is these pockets may be due to the presence of fluoride rich minerals like fluorite and appetite.

8. The groundwater of Sundarapuram and Uvari is identified as the most polluted in both the seasons. Basin authority may give priority to these places while implementing groundwater improvement measures. Based on the present stud, Pudukulam is identified as a potable source for the entire year. Ittamozhipudur, Mannarpuram vilakku, Munanjipatti, Radhapuram, and Samugarengapuram are identified as less contaminated areas from this study. Hence the developmental activities in terms of agriculture or water resources development can be carried out in the above places.

9. From the water quality trends study using the surface and groundwater quality parameters, it is seen that the basin is getting polluted with time. Since major industries are not present in the basin or other pollution sources, the natural

geochemistry of the basin is the reason for the higher level of Hardness which increases with time.

10. The detailed statistical study on water quality reveals that Chloride, Calcium, Shulphate and Sodium show a good correlation with TDS. Thus the regression equation formed from the study can be used to find the approximate value of these four water qualities by using TDS.

11. The WQI study on this basin shows that most of the water (90 % of the water sources) can be used for different purposes. The Calcium, TDS, and Hardness are the major pollutants which cause the remaining 10% of the water sources unfit for potable purposes.

12. This study also reveals that the ANN-based GIS-coupled IPM exhibits robustness and reliable performance in predicting the TDS, Chloride and Hardness with EC and Magnesium as the input parameters. It is also compared with the statistical model and it is concluded that the ANN-based Intelligent Predictive Model gives better results for this study area.

13. The Water quality monitoring of Nambiyar River basin has been simplified by constructing ANN-based water quality models. These models are capable of determining parameters such as TDS, Chloride and Hardness using easy-to-determine parameters such as EC and Magnesium.

14. Decision makers and river basin managers associated with Nambiyar basin will do well to use the findings of this thesis as a decision support tool. It may be concluded that Nambiyar

basin is not yet polluted with industrial effluents compared to nearby river basins. The primary factors contributing to the present situation are presence of small number of industries and migration of population from this river basin to urban areas.

15. Since the ANN based model is purely based on the exist data, the methodology may be used for the other basins, based on the availability of the data.

The following measures can be suggested after analyzing the various data and also by considering the realities of the ground conditions:

- Water conservation structures and harvesting structures can be promoted especially in the eastern area of the basin. Less water consuming crops can be irrigated in the summer period and in the low rainfall period. Judicious utilization of water resources is the prime need of the hour in the entire basin area.

- Equitable distribution of irrigation water by better water management,

- Improving the performance of existing irrigation system by suitable structural measures,

- Introducing micro-irrigation like drip-and sprinkler-irrigation,

- Conjunctive use of surface and groundwater wherever possible,

- Renovating old tanks and ponds, desilting of supply channels and constructing water harvest structures to improve irrigation potential,

- Planning for rainwater harvesting and saving surface water, which is let into sea during floods,

- Adopting better agricultural practices such as crop rotation, rising garden crops and other less water-consuming crops,

- Large scale extraction should be avoided especially in the coastal region of the basin in order to avoid intrusion of seawater into the inland areas.

- Water level of should be necessarily maintained as 1m above MSL especially in the coastal areas of the basin.

- Works relating to rehabilitation of tanks should be initiated in the coastal areas especially in water-scarcity areas of the basin.

- Spacing norms between the wells should be strictly adhered.

- Groundwater extraction can be restricted so as to fix the horse power of motor within a desired limit wherever the areas to be over-extraction areas.

- Prioritization should be given in the over-extracted areas in the basin so as to conserve the water and for planning appropriate harvesting structures to be put into action.

- Popularize the awareness programmes among the public, especially farmers at various levels, which should be made effective so as to attain self sufficiency in the sustainable water resources development.

This work has demonstrated that hydro-geochemical studies, water quality trends and water quality prediction modelling help in better evaluation of the basin. The above results can be used for future sustainable development of the basin by the basin authorities and decision makers.

Based on the present study it has been found that water resources potential evaluation in terms of quantification of groundwater is essential to evolve water resources development plans for the basin. Keeping the above idea in mind a project proposal entitled “Study on recharge characteristics of tanks in the semi-arid zone using isotope techniques and conventional hydrological models has been submitted to the Department of Science and Technology (DST), Government of India, and the DST has sanctioned Rs.17,17,000/ to carry out the above study with the author as the principle investigator (DST LTR.No.SR/S3/ENGF-01/2002 Dt: 16th November 2010). The project is already underway.

9.3 SCOPE FOR FUTURE WORKS

- The modelling study can be extended for the other water quality parameters.

- A study on groundwater quality movement can be carried out.

- A detailed study on consumptive use of ground water can be carried out.

APPENDIX

```
1000 PRINT " ************************************************************"
1010 PRINT " *                                                          *"
1020 PRINT " *                                                          *"
1030 PRINT " *            SIMPLE BASIC COMPUTER PROGRAM                 *"
1040 PRINT " *             FOR THE CLASSIFICATION OF                    *"
1050 PRINT " *      HYDROGEOCHEMICAL FACIES OF GROUNDWATERS             *"
1060 PRINT " *                                                          *"
1070 PRINT " *                                                          *"
1080 PRINT " ************************************************************"
1090 DIM ARRAY$(10), E(10), NN(10), SS(10, 10), CLASS$(20), X(95), Y(10),
Z(10)
1100 DIM A$(6), C$(5), S$(5), T$(5), CF(10), P(10), CD(10), FF(10), BB(10)
1110 DIM F1(10), F2(10), HP(10), EW(10), B$(10), RES$(10), AA$(90)
1120 DATA ALK-VERY LOW,ALK-LOW,ALK-MODERATELY LOW,ALK-MODERATE,ALK-MOD-
HIGH,ALK-HIGH,ALK-VERY-HIGH,ALK-EXTREMELY HIGH,ALK-EXT-HIGH,ALK-EXTR-
HIGH,ALK-EXT-HIGH
1130 FOR L = 1 TO 11: READ CLASS$(L): NEXT L
1140 DATA A1,A2,A3,B1,B2,B3,C1,C2,C3,C4,C5,S1,S2,S3,S4,S5,  O,  I, II,III,
IV
1150 DATA 20.04,12.15252,23,61.02,30.001,35.453,62,48.03
1160 DATA 40.08,24.32,23,61.02,60.01,35.457,62.01,96.07,2,2,1,1,2,1,1,2
1170 DATA .5399508,-.1243334,-7.752454E-03,2.367353E-03,4.477692E-04,-
3.728097E-05,-1.388233E-05,-8.311549E-07,5,6,4,0,0,3,1,2,0,2.5,7.5,22.5,25
1180 DATA 8.484292E-02,-8.354048E-02,2.505801E-02,7.745833E-03,1.172078E-
03,-9.501622E-05,-4.951132E-05,-3.706292E-06
1190 DATA 7.943,6.31,5.012,3.981,3.162,2.512,1.995,1.585,1.259,1.0
1200 DATA 9,9,9,9,9,9,9,8,8,8,9,9,9,9,9,9,8,8,8,4,4,4,4,4,5,8,8,8
1210 DATA 4,4,4,4,4,5,5,5,7,7,4,4,4,4,5,5,5,6,7,7,4,4,4,5,5,5,6,6,7,7
1220 DATA 3,3,5,5,5,6,6,6,7,7,3,3,5,5,6,6,6,6,7,7,1,1,2,2,2,2,2,2,6,6
1230 DATA 1,1,2,2,2,2,2,2,6,6
1240 DATA "RECENT RECHARGE WATER","ION EXCHANGE","RECENT DOLOMITIC
WATERS","STATIC AND DISCO-ORDINATED REGIMES","DISSOLUTION AND
MIXING","DYNAMIC AND CO-ORDINATED REGIMES"
1250 DATA "CONCENTRATION & PRECIPITATION","SEA-WATER","WATERS CONTAMINATED
WITH GYPSUM"
1260 FOR J = 1 TO 6: READ A$(J): NEXT J: FOR K = 1 TO 5: READ C$(K): NEXT K
1270 FOR J = 1 TO 5: READ S$(J): NEXT J: FOR K = 1 TO 5: READ T$(K): NEXT K
1280 FOR J = 1 TO 8: READ CF(J): NEXT J: FOR K = 1 TO 8: READ CD(K): NEXT K
1290 FOR J = 1 TO 8: READ FF(J): NEXT J: FOR K = 1 TO 8: READ F1(K): NEXT K
1300 FOR J = 0 TO 7: READ NN(J): NEXT J: FOR K = 1 TO 5: READ NP(K): NEXT K
1310 FOR J = 1 TO 8: READ F2(J): NEXT J: FOR K = 1 TO 10: READ HP(K): NEXT
K
1320 FOR I = 1 TO 10: FOR J = 1 TO 10: READ SS(I, J): NEXT J: NEXT I
1330 FOR I = 1 TO 9: READ RES$(I): NEXT I
1340 REM INPUT DATA SECTION     DEFINITION OF VARIABLES:
1350 REM NA$=ID.CODE; EC=ELEC.CONDUCT(mmhos);  PH=pH;
1360 REM ARRAY E :  1-Ca  2-Mg  3-Na+K  4-HCO3  5-CO3  6-Cl
1370 REM            7-NO3 8-SO4
1380 REM TDS(ppm) ; T=Temp(deg.cent); ORP & DO as measured.
     OPEN "O", #2, "JFL1.TXT"
     OPEN "O", #3, "JFL2.TXT"
     OPEN "O", #4, "JFL3.TXT"
     OPEN "o", #1, "JFL4.TXT"
     INPUT " NO OF DATA SETS "; NN
     FOR II = 1 TO NN
1397 ORP = 0: T = 25: DDO = 0
   READ NA$, EC, PH: FOR J = 1 TO 8: READ E(J): X(J) = E(J): Y(J) = CF(J):
NEXT J: READ TDS: IF TDS = 0 THEN TDS = EC * .64
```

```
 TSC = 0: TSA = 0: PRINT TDS: PE = 23 * -.16 * TDS
 IF TDS > 100 THEN PE = 9 - .01 * TDS
 IF TDS > 200 THEN PE = 5.666667 - .0033 * TDS
 IF TDS > 500 THEN PE = 5 - .002 * TDS
 IF TDS > 1000 THEN PE = 4 - .001 * TDS
 IF TDS > 4000 THEN PE = 1.5
 FOR J = 1 TO 3: Z(J) = X(J) / Y(J): TSC = TSC + Z(J): NEXT J
 FOR J = 4 TO 8: Z(J) = X(J) / Y(J): TSA = TSA + Z(J): NEXT J
 OPE = ABS(TSC - TSA) / (TSC + TSA) * 100: IF OPE < PE THEN PRINT "
SAMPLE OK  " ELSE PRINT "  ERROR IN ANALYSIS";
 IF OPE > PE THEN 1398 ELSE 1430
1398  FOR J = 1 TO 3: Z(J) = TSA / TSC * Z(J): X(J) = INT(Z(J) * Y(J)):
E(J) = X(J): PRINT USING "####."; X(J); : NEXT J
1430 '
1440 FOR J = 1 TO 8: P(J) = E(J): NEXT J
     FOR J = 1 TO 8: PRINT #3, USING "#####"; E(J); : NEXT J: PRINT #3, "
"

PRINT #4, EC; : FOR JJ = 1 TO 6: PRINT #4, ","; : PRINT #4, USING "####";
E(JJ); : NEXT JJ: PRINT #4, ","; E(8)

FOR JJ = 1 TO 6: PRINT #1, USING "####"; E(JJ); : PRINT #1, ","; : NEXT JJ:
PRINT #1, E(8)

1450 GOSUB 3190
1460 PRINT #2, "SAMPLE CODE="; NA$: GOSUB 3190
1470 PRINT #2, "EC(mmhos)  ="; EC, "TDS (ppm)     ="; TDS
1480 PRINT #2, "pH         ="; PH, "ORP           ="; ORP
1490 PRINT #2, "DDO         ="; DDO, "Temp.(centig) ="; T
1500 IF TDS = 0 THEN TDS = EC * .64
1510 AC = .001: SS = 0!
1520 FOR J = 1 TO 8
1530 EW(J) = P(J) * AC / CD(J): SS = SS + EW(J) * FF(J) ^ 2: NEXT J
1540 ISS = .5 * SS: SS = LOG(SS): Y1 = F1(1): Y2 = F2(1)
1550 FOR IC = 2 TO 8: Y1 = Y1 + F1(IC) * (I9 ^ (IC - 1)): Y2 = Y2 + F2(IC)
* (I9 ^ (IC - 1)): NEXT IC
1560 RH = Y1: RCA = Y2: IX = INT((PH - FRAC(PH) - 1))
1570 C$ = MKS$(PH): Z$ = RIGHT$(C$, 1): PP = VAL(Z$): IX2 = PP
1580 IF PP = 0 THEN IX2 = 10
1590 FC = HP(IX2) * (10 ^ (-IX))
1600 CAC = FC * 40.08 * 10 ^ 3 / (EW(4) * RH * RCA): CAIND = (E(1) - CAC) /
E(1)
1610 A1 = -LOG(EW(1)) / 2.303: A2 = -LOG(EW(4)) / 2.303
1620 PHC = A1 + A2 + 1.9: DPH = PH - PHC: HYION = DPH: GOSUB 3190
1630 PRINT #2, "Conc/Ion    Ca    Mg   Na+K    HCO3     CO3    Cl    NO3
SO4"
1640 GOSUB 3190
1650 PRINT #2, "ppm     "; : FOR J = 1 TO 8: PRINT #2, USING "#####.#";
P(J); : NEXT J: PRINT #2,
1660 CR = ((E(6) / 35.5) + (E(8) / 48)) / ((E(4) + E(5)) / 50): FOR J = 1
TO 8: E(J) = E(J) / CF(J): P(J) = E(J): NEXT J
1670 PRINT #2, "epm     "; : FOR J = 1 TO 8: PRINT #2, USING "#####.#";
E(J); : NEXT J: PRINT #2,

1680 CA = E(1): MG = E(2): NAK = E(3): HCO3 = E(4): CO3 = E(5): CL = E(6):
NO3 = E(7): SO4 = E(8)
1690 SUM1 = 0: FOR J = 1 TO 3: SUM1 = SUM1 + E(J): NEXT J: TSC = SUM1: PE =
23 - .16 * TDS
1700 SUM1 = 0: FOR J = 4 TO 8: SUM1 = SUM1 + E(J): NEXT J: TSA = SUM1: DIF1
= ABS(TSC - TSA)
1710 IF TDS > 100 THEN PE = 9 - .01 * TDS
1720 IF TDS > 200 THEN PE = 5.66667 - .0033 * TDS
1730 IF TDS > 500 THEN PE = 5 - .002 * TDS
1740 IF TDS > 1000 THEN PE = 4 - .001 * TDS
1750 IF TDS >= 4000 THEN PE = 1.5
```

```
1760 DIF2 = DIF1 / (TSC + TSA) * 100: PV = DIF2: US$ = "S4": SL$ = "C5"
1770 IF DIF2 - PE <= 0 THEN 1780 ELSE PRINT "ERROR IN ANALYSIS ": PRINT
"TSA="; TSA, "TSC="; TSC: PRINT " PE="; PE, "OBS ERROR="; DIF2: STOP
1780 CLA1 = (E(6) - E(3)) / E(6): CLA2 = (E(6) - E(3)) / (E(8) + E(5) +
E(4) + E(7)): SAR = E(3) / SQR((E(1) + E(2)) / 2)
1790 PT1 = 10 ^ (4.9753 - .1144 * SAR): PT2 = 10 ^ (4.6252 - .1458 * SAR):
PT3 = 10 ^ (4.1878 - .2188 * SAR)
1800 IF EC < PT1 THEN US$ = "S3"
1810 IF EC < PT2 THEN US$ = "S2"
1820 IF EC < PT3 THEN US$ = "S1"
1830 IF EC < 4000 THEN SL$ = "C4"
1840 IF EC < 2250 THEN SL$ = "C3"
1850 IF EC < 750 THEN SL$ = "C2"
1860 IF EC < 250 THEN SL$ = "C1"
1870 R1 = E(4) + E(5): R2 = (E(1) + E(2)): RSC = R1 - R2: NCH = (R2 - R1) *
50: PPI = (E(3) + SQR(E(4))) / (R2 + E(3)) * 100: FOR L = 1 TO 4: ARRAY$(L)
= " ": NEXT L
1880 E(1) = E(1) / TSC * 100: E(2) = E(2) / TSC * 100: E(3) = E(3) / TSC *
100: TEST = E(5)
1890 E(4) = E(4) + E(5): FOR J = 4 TO 8: E(J) = E(J) / TSA * 100: NEXT J
1900 E(5) = TEST: FAC1 = E(1) + E(2): FAC3 = E(6) + E(8): II1 = 1: II2 = 1:
II3 = 1
1910 IF FAC1 > E(4) THEN 1930
1920 II1 = 0
1930 IF FAC1 > E(3) THEN 1950
1940 II2 = 0
1950 IF FAC3 > E(4) THEN 1970
1960 II3 = 0
1970 NET = II3 + 2 * II2 + 4 * II1: ARRAY$(1) = A$(NN(NET))
1980 FOR J = 1 TO 5: IF TSC > NP(J) THEN ARRAY$(2) = C$(J)
1990 NEXT J
2000 ARRAY$(3) = S$(2): MECH$ = "EVAPORATION": ARRAY$(4) = T$(1)
2010 SS1 = -2.667812142# * TSC + 99.08018328#: SS3 = -1.73434517# * TSC +
100.765273#
2020 IF E(3) <= SS1 THEN ARRAY$(3) = S$(1)
2030 IF E(3) > SS3 THEN ARRAY$(3) = S$(3)
2040 RA1 = P(6) / (P(6) + P(4)): RA2 = P(3) / (P(3) + P(1))
2050 PL1 = 10 ^ (2.7217 + .9068 * RA1): PL2 = 10 ^ (1.9567 + .17615 * RA1)
2060 IF TDS < PL1 THEN MECH$ = "ROCK INTERACTION"
2070 IF TDS < PL2 THEN MECH$ = "PRECIPITATION   "
2080 PRINT #2, " %      "; : FOR J = 1 TO 8: PRINT #2, USING "#####.#";
E(J); : NEXT J: PRINT #2,
2090 GOSUB 3190
2100 REM IF E(5)=0 AND E(5)=E(8) THEN 2090 ELSE 2100
2110 REM IF E(5)=0 AND E(8)=0 THEN 2090 ELSE 2100
2120 REM ARRAY$(4)=T$(4):GOTO 2160
2130 IF P(5) > P(8) THEN 2160
2140 IF P(8) > P(6) THEN 2170
2150 IF P(6) > P(8) AND E(8) > E(5) THEN 2180
2160 ARRAY$(4) = "  I": GOTO 2220
2170 ARRAY$(4) = " II": GOTO 2220
2180 ARRAY$(4) = "III"
2190 IF P(3) > P(2) AND P(2) > P(1) THEN 2210 ELSE 2200
2200 ARRAY$(4) = "III": GOTO 2220
2210 ARRAY$(4) = " IV"
2220 AA = E(3): BB = E(6) + E(8): Q$ = " Ca+Mg": R$ = " Na+K": P$ = Q$: X$
= " HCO3+CO3": Y$ = " Cl+SO4": Z$ = X$
2230 IF AA > 20 THEN P$ = Q$ + "," + R$
2240 IF AA > 50 THEN P$ = R$ + "," + Q$
2250 IF AA > 80 THEN P$ = R$
2260 IF BB > 20 THEN Z$ = X$ + "," + Y$
2270 IF BB > 50 THEN Z$ = Y$ + "," + X$
2280 IF BB > 80 THEN Z$ = Y$
2290 I = INT(E(4) / 10): J = INT(AA / 10): IF I = 0 THEN I = 1
2300 IF J = 0 THEN J = 1
```

```
2310 EN = SS(I, J)
2320 H = 10 ^ (3! - PH): TK = T(I) + 273.15
2330 MU = .0005 * (CL + HCO3 + NO3 + H + NAK + 2 * (SO4 + CO3 + CA + MG))
2340 GAM1 = 10 ^ (-.05 * (SQR(MU) / (SQR(MU) + 1) - .3 * MU))
2350 SAN = TSA: SKAT = H / GAM1 + TSC
2360 SA$ = "G-V.OLIGOHALINE "
2370 IF CL > .141 THEN SA$ = "g-Oligohaline "
2380 IF CL > .846 THEN SA$ = "F-Fresh "
2390 IF CL > 4.231 THEN SA$ = "f-Fresh-brackish"
2400 IF CL > 8.462 THEN SA$ = "B-Brackish "
2410 IF CL > 28.206 THEN SA$ = "b-Brackish-salt"
2420 IF CL > 282.064 THEN SA$ = "S-Salt "
2430 IF CL > 564.127 THEN SA$ = "H-Hyperhaline"
2440 ALK = HCO3 + CO3: ALKFI = INT(LOG(ALK) / LOG(2) + 1)
2450 B$ = CLASS$(ALKFI + 2)
2460 IF ALK > 256 THEN B$ = CLASS$(11)
2470 IF ALK <= 1 THEN B$ = CLASS$(2)
2480 IF ALK <= .5 THEN B$ = CLASS$(1)
2490 SNO3 = NO3: HZ = H / GAM1
2500 OHC = (10 ^ (12.0875 - .01706 * TK - 4470.099 / TK)) / (H * GAM1)
2510 CO3F = CO3 - OHC
2520 IF NAK > (SKAT / 2) THEN 2530 ELSE 2570
2530 IF NH4 > NAK THEN 2540 ELSE 2550
2540 S1$ = "NH4": GOTO 2560
2550 S1$ = " NA+K"
2560 GOTO 2610
2570 IF (CA + MG) > HZ THEN 2580 ELSE 2610
2580 IF MG >= CA THEN 2590 ELSE 2600
2590 S1$ = " Mg": GOTO 2610
2600 S1$ = "Ca "
2610 IF CL > (SAN / 2) THEN 2620 ELSE 2630
2620 S2$ = "Cl": GOTO 2720
2630 IF ALK > (SAN / 2) THEN 2640 ELSE 2680
2640 IF HCO3 > CO3 THEN 2650 ELSE 2660
2650 S2$ = " HCO3": GOTO 2720
2660 IF CO3F > OHC THEN S2$ = " CO3" ELSE S2$ = " OH"
2670 GOTO 2720
2680 IF (SO4 + SNO3) > (SAN / 2) THEN 2690 ELSE 2710
2690 IF SO4 > SNO3 THEN S2$ = " SO4 " ELSE S2$ = "NO3"
2700 GOTO 2720
2710 S2$ = " Mixed"
2720 SC$ = "  "
2730 NAKMG = NAK + MG - 1.0716 * CL
2740 IF NAKMG > SQR(.5 * CL) AND NAKMG > (1.5 * (SKAT - SAN)) THEN 2760
ELSE 2770
2750 IF NAKMG > (1.5 * (SKAT - SAN)) THEN 2760 ELSE 2770
2760 SC$ = "(+) Na+Mg SURPLUS INDICATES FRESHWATER INTRUSION-ANYTIME
ANYWHERE ": GOTO 2830
2770 IF NAKMG < (-SQR(.5 * CL)) AND NAKMG < (1.5 * (SKAT - SAN)) THEN 2790
ELSE 2800
2780 IF NAKMG < (1.5 * (SKAT - SAN)) THEN 2790 ELSE 2800
2790 SC$ = "(-) Na+Mg DEFICIT INDICATE SALT WATER INTRUSION-ANYWHERE-
ANYTIME ": GOTO 2830
2800 IF SKAT = SAN THEN 2810 ELSE 2820
2810 SC$ = "(.) Na+Mg EQUILIBM INDICATE ADEQUATE FLUSHING WITH WATER OF
CONST.COMP ": GOTO 2830
2820 IF (ABS(NAKMG + SQR(.5 * CL) * (SKAT - SAN) / ABS(SKAT - SAN)) >
ABS(1.5 * (SKAT - SAN))) THEN SC$ = "(.) Na&Mg EQBM INDICATE ADEQUATE
FLUSHING WITH WATER OF CONST.COMP " ELSE SC$ = " "
2830 PRINT
2840 PRINT #2, "Sodium Adsorption Ratio ="; SAR: PRINT #2, "Residual Sodium
Carbonate="; RSC
2850 PRINT #2, "Non-carbonate Hardness  ="; NCH: PRINT #2, "Permeability
Index(Doneen)="; PPI
```

```
2860 PRINT #2, "IONIC STRENGTH ="; USING "###.####"; ISS; : PRINT #2, "
CORROSIVITY RATIO ="; USING "###.####"; CR
2870 PRINT #2, "INDICES OF BASE EXCHANGE ="; USING "#####.####"; CLA1;
CLA2: PRINT #2,
2880 PRINT #2, "          CaCO3 SATURATION INDICES :": PRINT #2,
"Equilibrium Ca method="; USING "###.####"; CAIND; : PRINT #2, "
Equilibrium pH method="; USING "###.####"; HYION
2890 PRINT #2, "GIBB'S PLOT : MECHANISM CONTROLLING THE CHEMISTRY =  ";
MECH$
2900 DD$ = "Moderate"
2910 IF LEFT$(ARRAY$(1), 1) = "A" THEN D$ = "Permanent" ELSE D$ =
"Temporary"
2920 IF RIGHT$(ARRAY$(2), 1) = "1" THEN DD$ = "V.Low"
2930 IF RIGHT$(ARRAY$(2), 1) = "2" THEN DD$ = "Low "
2940 IF RIGHT$(ARRAY$(2), 1) = "4" THEN DD$ = "High"
2950 IF RIGHT$(ARRAY$(2), 1) = "5" THEN DD$ = "V.High"
2960 GOSUB 3190: PRINT #2, "          HANDA'S CLASSIFICATION :": PRINT #2,
"Hardness        =; ARRAY$(1); "   "; D$: PRINT #2, "Salinity         =";
ARRAY$(2); "   "; DD$
2970 DD$ = "Low": IF RIGHT$(ARRAY$(3), 1) = "2" THEN DD$ = "Moderate"
2980 IF RIGHT$(ARRAY$(3), 1) = "3" THEN DD$ = "High"
2990 D$ = "rCl > rSO4 > rCO3 and rNa > rMg > rCa"
3000 IF ARRAY$(4) = "  I" THEN D$ = "rCO3 > rCl OR rSO4"
3010 IF ARRAY$(4) = " II" THEN D$ = "rSO4 > rCl"
3020 IF ARRAY$(4) = "III" THEN D$ = "rCL > rSO4 > rCO3"
3030 IF ARRAY$(4) = " IV" THEN D$ = "rCl > rSO4 > rCO3 and rNa > rMg > rCa"
3040 PRINT #2, "Sodium hazard   =; ARRAY$(3); "   "; DD$: GOSUB 3190:
PRINT #2, "SCHOELLER'S WATER TYPE (r=epm)": PRINT #2, "      "; ARRAY$(4);
"  Since   "; D$
3050 GOSUB 3190: PRINT #2, "          PIPER'S HYDROGEOCHEMICAL FACIES:":
PRINT #2, "Cations  =; P$, "Anions       =; Z$
3060 PRINT #2, "SIGNIFICANT ENVIRONMENT : "; RES$(EN)
3070 GOSUB 3190: PRINT #2, "          STUYFZAND'S CLASSIFICATION:"
3080 PRINT #2, "WATER TYPE(Based on Cl) ="; SA$: PRINT #2, "SUB-TYPE(Based
on Alk) ="; B$
3090 PRINT #2, "FACIES        ="; S1$; "  "; S2$
3100 PRINT #2, "SIGNIFICANT ENVIRONMENT : ": PRINT #2, SC$
3110 GOSUB 3190: PRINT #2, "          USSL CLASSIFICATION : "
3120 PRINT #2, "Salinity      ="; SL$, "Sodium hazard = "; US$
3130 GOSUB 3190
3140 PRINT #2,
3150 NEXT II
3160 CLOSE #3: CLOSE #2: CLOSE #4: CLOSE #1
3170 STOP
3180 REM
3190 FOR KK = 1 TO 70: PRINT #2, "-"; : NEXT KK: PRINT #2, : RETURN
5001 DATA MAGDI DW,741,7.60,55.3,4.86,29,285,60,49.7,0,17.5,474

1      Kadambakudi         1080   8.1    22     6      210.5  320    0      82
       57     708
2.       Thondi Road              2360    8.32    32      10      529     432
40       451     86      1665

3      Thondi              5104   7.95   112    53     945    448    0
       1372   204    3530
4      Vattanam            4358   7.56   160    46     768    340    0
       1225   172    3030
5      Keelakurichi        946    7.72   67     25     97.6   276    0
       110    17     662
6      R.S.Mangalam        635    7.52   30     7      105.6  240    0      39
       20     442
7.       Paranur                 346     7       16      6       53.4    136
0       20      9       250
```

8	Paranur-Uppur Rd.	3807	8.13	116	38	639	416	0	921 211 2660
9	Uranankudi	359	8.04	19	7	42	156	0	17 11 244
10	Uppur	4409	7.4	78	32	787	292	0	1200 255 3030
11	Devipatinam	2775	7.84	110	42	513	408	0	608 141 1964
12.	Mohamadiyapuram	4471	8.37	64	26	860	292	48	1249 315 3104
13	Uttrakosaimangai	6258	8.12	112	48	1290	248	0	1813 639 4304
14	Nallinerukai	6698	8.13	148	43	1244	248	0	1862 774 4600
15.	Mariaroyapuram	997	7.62	46	14	124	380	0	92 28 690
16	Idambadal	6280	8.13	192	58	1170	284	0	1911 444 4320
17	Ervadi	1412	7.63	32	11	260.5	348	80	102 71 980
18	Chinna Ervadi	2680	7.78	156	41	299	216	0	102 111 1930
19	Periapattinam	2887	8.48	152	48	334	264	0	706 113 2040
20	Muthupettai	381	7.64	34	12	24.5	126	0	34 13 250
21.	Raghunathapuram	9071	7.99	192	62	1855	956	0	2548 466 5364
22.	Valudur	2191	8.1	82	35	318.5	436	0	397 85 1540
23	Chenkalanir Oodai	644	7.45	64	21	33.5	216	0	43 8 496
24.	Mandabam Camp	3500	8.25	172	74	396	348	0	666 306 2454
25	Idayarvalasai	909	7.98	85	26	78.8	276	0	88 66 630
26	Ariyaman	682	8.22	44	19	70.5	224	0	74 15 476
27	Maravettivalasai	751	7.99	64	18	59.2	176	0	94 37 540
28	Perunkulam	1641	8.38	33	9	326	420	64	230 58 1160
29	Tirupulani	954	8.6	46	12	139	184	96	133 27 660
30.	Sakkarh)	966	8.07	48	16	147.4	340	0	82 20 674
31	Sikkal	1197	8.1	44	15	170	292	0	167 10 804
32	Kusavankulam	5625	7.79	244	113	760	296	0	1225 408 3882
33	Volinokkam	10126	7.9	244	113	1482	384	0	3038 785 7344
34	Vadakkumukkaiyur	6254	8.05	160	79	1188	464	0	1764 379 4662
35	Sayalkudi	16680	8.23	576	211	4500	536	0	8526 1777 24304
36	Naraippaiyur	1593	8.08	80	45	154.6	224	0	279 83 1104

37.	Terkukadusandai		3228	8.32	148	50	429.5	208	40	804	161	2270
38	Kadaladi	25578	8.37	760	252	4620	220	56	6370	7862	18830	
39	Kandilan	28224	7.85	820	288	4840	232	0	7546	7938	19560	
40.	Appanur		1189	8.43	34	11	178.8	296	72	100	128	840
41	Nombakulam	1189	8.23	54	23	168.2	356	0	129	57	820	
42	Kanikkur	6309	8.31	192	58	1280	748	0	1332	718	4320	
43	Kovilankulam	6350	8.25	152	48	1314	724	0	1342	745	4308	
44.	Neyvoil		1594	8.06	40	17	276	192	0	466	40	1120
45	Mangalakudi	1414	8.15	30	8	242.5	192	0	317	26	976	
46	Karkathakudi	1753	8.2	40	14	347	244	0	416	50	1224	
47	Janaveli	1794	8.23	66	20	307.5	356	0	343	86	1256	
48	Irudayapuram	1289	8.13	61	16	158.6	432	0	108	47	830	
49	Pottagavoil	2050	8.15	34	12	409.5	436	0	367	128	1442	
50	Poragudi	690	8.38	32	10	89	228	48	34	21	476	

REFERENCES

1. Achuthan Nair, G., Abdullah Mohamad and Mahamoud Mahdy Fadiel "Physio-chemical parameters and correlation coefficients of ground waters of North-East Libya", Pollution Research, Vol. 24, No.1, pp. 1-6, 2005.

2. Ahamed, S., David, K.S. and Gerald, S. "Environmental assessment; an innovation indeed for evaluation water quality in streams", Environmental management, Vol. 34, pp. 406-414, 2004.

3. Aiuppa, A., Allard, P. D., Alessandro, W., Michel, A., Parello, F., Treuil, M. and Valenza, M. "Mobility and fluxes of major, minor and trace metals during basalt weathering and groundwater transport at Mt.Etanvolcan (sieity)", Geochem. Cosmochim. Acta., Vol. 64, pp. 1827-1841, 2000.

4. Akhtar, M.K., Corzo1, G.A., Van Andel, S. J. and Jonoski, A. "River flow forecasting with artificial neural networks using satellite observed precipitation pre-processed with flow length and travel time information: Case study of the Ganges river basin", Hydrol. Earth Syst. Sci., Vol. 13, pp. 1607-1618, 2009.

5. Alam, Md. J.B., Muyen, Z., Islam, M. R., Islam, S. and Mamun, M. "Water quality parameters along rivers", Int. J. Environ. Sci.Tech., Vol. 4, No. 1, pp. 159-167, 2007.

6. Alam, Md. J.B., Muyen, Z., Islam, M. R., Islam, S. and Mamun, M. "Water quality parameters along rivers," Int., J., Environ., Sci., Tech., Vol.4 No.1, pp.159-167, 2007.

7. Altman, D.G. "Practical Statistics for Medical Research", 2nd Ed, Wiley, London, 1991.

8. American Public Health Association "American Waterworks Association, and Water Pollution Control Federation. Standard methods for the examination of water and wastewater", American Public Health Association, Washington, D.C,1989.

9. American Public Health Association "Standard methods for the examination of water and wastewater. American Public Health Association, American Water Works Association, and Water Pollution Control Federation", 19th edition, Washington, D.C, 1995.

10. Anonymous "Interim National Water Quality Standards for Malaysia, Department of Environment" (online) http://www.jas.sains.my/jas/rivrt /interim_2-3c.htm., 1997.

11. APHA – AWWA and WPCF "Standard Methods for the Examination of Water and Wastewater", 16th Ed. Washington D.C, APHA, pp.1268, 1984.

12. Aravinda, H.B. "Correlation coefficient of some Physico-chemical parameters of river Tugabhadra, Karnataka", Pollution Research, Vol. 17, No. 4, pp. 371-375, 1991.

13. Ayer and Westcot "Water quality for agriculture, irrigation and drianage", Paper No. 29, Rev.1, FAO, Rome, pp.174, 1985.

14. Ayman, F. and Batisha "Water qulity sensing using multi-layer perceptron artificial neural networks", www.eeaa.gov.eg/english/main /Env2003/Day2/Water/batisha.nwri.pdf, 2003.

15. Back, W. and Hanshaw, B.B. "Chemical geohydrology", Advances in Hydroscience, Academic Press,New York, Vol. 2, pp.49–104, 1965.

16. Balasubramaniam, A. and Sastri, J.C.V. "Studies on the quality of groundwater of Tambaraparani River basin, Tamil Nadu", Nat, Semi, Groundwater Mang, Tamil Nadu, Agricultural University, Coimbatore, pp.124-128, 1985.

17. Balasubramanian, A., Subramanian, S. and Sastri, J.C.V. "HYCH – Basic computer program for Hydrochemical studies", Proc. Vol. Nat. Sem. On water. Govt. of Kerala, Trivandrum, 1991b.

18. Balsubramanian, A., Thirugnana Sambandam, R., Chellasamy, R. and Radhakrishnan, V. "Hydro-geochemical studies in coastal aquifer of Tuticorin, Tamil Nadu", Proc. Vol. on Seminar on Dev. Man. of Groundwater in Irrigation and Other Water Sectors, CWRDM, pp.309-317, 1991.

19. Bandyopadhyay, G. and Chattopadhyay, S. "Single hidden layer artificial neural network models versus multiple linear regression model in forecasting the time series of total ozone," Int. J. Environ. Sci. Tech., Vol. 4, No. 1, pp. 141-149, 2007.

20. Basnyat, P., Teeter, L.D., Lockaby, B.G. and Flynn, K.M. "The use of remote sensing and GIS in watershed level analyses of non-point source pollution problems," Forest Ecology and Management, Vol. 128, pp. 65-73, 2000.

21. Bateman, A. 'Economic Mineral Deposits', Asia Publishing, New York, pp.788, 1960.

22. Biswal, S.K., Maythi, B. and Behera, J.P. "Ground water quality near ash pond of thermal power plant", Pollution Research, Vol. 20, No.3, pp.487-490, 2001.

23. Boritz, J. F. and Kennedy, D.B. "Effectiveness of neural network types for prediction of business failure", Expert Systems with Applications, Vol. 9, pp. 503-512, 1995.

24. Bowers, J.A. and Shedrow, C.B. "Predicting stream water quality using artificial neural networks", U.S. Department of Energy Report WSRC-MS-2000-00112, pp.7-14, 2000.

25. Brown, R.M., McClelland, N.I., Deininger, R.A. and Tozer, R.G. "A Water quality index – Do we dare?", Water and Sewage Works, pp. 339-343, 1970.

26. Buntine, W.L. and Weigend, A.S. 'Bayesian Back-propagation', Complex Systems, Vol. 5, pp. 603-643, 1991.

27. Campbell, M.J. and Machin, D. "Medical Statistics A Commonsense Approach", 2nd Ed. Wiley, London, 1993.

28. Carroll, D. "Rainwater as a chemical agent of geologic processes – a review", U.S Geological Survey water supply paper 520-f, pp. 97-104, 1962.

29. Cerling, T.E., Pederson, B.L. and von Damm, K.L. "Sodium-calcium ion exchange in the weathering of shales: Implications for global weathering budgets", Geology, Vol. 17, pp. 552-554, 1989.

30. Chakraborty, K., Mehrotra, K., Mohan, C.K. and Ranka, S. "Forecasting the behaviour of multivariate time seires using neural network", Neural networks, Vol. 5, pp. 961-970, 1992.

31. Chandra Sekhar, M. and Satya Prasad, M.V.K. “Regression model for assessment of dissolved pollutants in Krishna river”, Journal of Indian Water Resources Society, Vol. 25, No. 4, pp. 46-49, 2005.

32. Chau K. wok-wing “A review on integration of artificial intelligence into water quality modelling”, Marine Pollution Bulletin, Vol. 52, pp. 726-733, 2006.

33. Chebotarev II. “Metamorphism of natural waters in the crust of weathering”, Parts 1-3. Geochim Cosmochim Acta, Vol. 8, pp. 22-48, 137-170, 198-212, 1955.

34. Chen Q Mynett, A.E. “Integration of data mining techniques and heuristic knowledge in fuzzy logic modelling of eutrophication in Taihu Lake”, Ecological Modelling, Vol. 162, No. 1/2, pp. 55-67, 2003.

35. Chenini, I. and Khemiri, S. “Evaluation of ground water quality using multiple linear regression and structural equation modeling”, Int. J. Environ. Sci. Tech., Vol. 6, No. 3, pp. 509-519, 2009.

36. Chimwanza , B., Mumba, P. P., Moyo, B. H. Z. and Kadewa, W. “The impact of farming on river banks on water quality of the rivers,” Int. J. Environ. Sci. Tech., Vol. 2, No. 4, pp. 353-358, 2006.

37. Chun, K. C., Chang, R. W. and Williams, G.P. “Water quality issues in the Nakdong River Basin in the Republic of Korea”, Journal of Environmental Engineering and Policy, Vol. 2, pp. 131-143, 2001.

38. Collet, C., Consuegra, D. and Joerin, F. “GIS Needs and GIS Software”, Kluwer Academic Publishers. pp.115-142, 1996.

39. Conway “Mean geochemical data in relation to oceanic evolution”, Geochim. Cosmochim, Acta, Vol. 8, pp. 22-48, 137-170, 198-212, 1942.

40. Couillard, D. and Lefebvre, Y. “Analysis of water quality indices”, Journal of Enviornment Management, Vol. 21, pp. 161-179, 1985.

41. Cude, C. “Oregon Department of Environmental Quality”, Laboratory Division Oregon EA (Online). http://www.deq.state.or.us/lab/wqm/wqi/wqindex.htm. 2003

42. Das, J. and Acharya, B.C "Hydrology and assessment of lotic water quality in Cuttack City, India", Water, Air, Soil Pollut., Vol. 150, pp. 163-175, 2003.

43. Dash, J.R., Dash, P.C. and Patra, H.K. "A Correlation and regression Study on the ground water quality in rural areas around Angul-Talcher Industrial zone", Indian Jorunal of Environmetnal Protection, Vol. 26, No. 6, pp. 550-558, 2006.

44. Davis and Dewiest "Hydrology", John Wiley, New York, pp.463, 1966.

45. Dethier, D.P. "A hydrogeochemical model for stream chemistry, Cascade Range, Washington, U.S.A", Earth Surface Recesses and Landforms, Vol. 13, pp. 321-333, 1988.

46. Dhembare, A. and Pondhe, G.M. "Correlation of ground waste quality parameters of Sonai area (Maharashtra)", Pollution Research, Vol. 16, No. 3, pp. 189-199, 1997.

47. Diamantopoulou Maria, J., Antonopoulos Vassilis, Z. and Papamichail Dimitris, M. "Cascade correlation artificial neural networks for estimating missing monthly values of water quality parameters in rivers", Water Resour Manage, Vol. 21, pp. 649-662, 2007.

48. Eddy El Tabach, Laurent Lancelot, Isam Shahrour and Yacoub Najjar "Use of artificial neural network simulation metamodelling to assess groundwater contamination in a road project", Mathematical and Computer Modelling, Vol. 45, pp. 766-776, 2007.

49. Edmunds, W.M. and Walton, N.R.G. "The Lioncolnshire limestone-Hydrogeochemical evolution over a ten year period", Journal of Hydrogeology, Vol. 61, pp. 201-122, 1983.

50. Elango, L. "Hydrogeochemistry and modelling of multilayer aquifers", Ph.D. Thesis, Anna University, Chennai, India, 1992.

51. Elango, L., Kannan, R. and Senthil Kumar, M. "Major ion chemistry and identification of hydrogeochemical processes of groundwater in a part of Kancheepuram District, Tamil Nadu, India", Environmental Geosciences, Vol. 10, No. 4, pp.157-166, 2003.

52. Elango, L., Rajmohan, N. and Gnanasundar, D. "Groundwater quality monitoring, in intensively cultivated regions of Tamil Nadu, India", Weaver T.R. and Lawrence C.R. (Eds.), Proceedings on Groundwater Sustainable Solution, University of Melborne, Australia, pp. 637-643, 1999.

53. El-shafie, A.E., Noureldin, M.R., Taha and Basri, H. "Neural network model for Nile River inflow forecasting analysis of historical inflow data", Journal of Applied Sciences, Vol. 8, No. 24, pp. 4487-4499, 2008.

54. Ferguson, R.I., Trudgill, S.T. and Ball, J. "Mixing and uptake of solutes in catchments: model development", Journal of Hydrology, Vol. 159, pp. 223-233, 1994.

55. Freeze, R.A. and Cherry, J.A. "Ground Water Floe", New Jersey, Prentice- Hall Inc., pp. 15-77, 1979.

56. Ganesh, R., Hegde and Kale, Y.S. "Quality of lentic waters of Dharwad District in North Karnataka", Indian J. Environ. Hlth., Vol. 37, No. 1, pp. 52-56, 1995.

57. Garg, D.K., Goyal, R.K. and Agarwal, V.P. "Correlation among water quality parameters of groundwater of Roorkee city", Indian Journal of Environmental Protection, Vol. 10, No. 5, pp. 355-359, 1990.

58. Gibbs, R.J. "Mechanisms controlling world's water chemistry", Science, Vol. 170, pp. 1088-1090, 1970.

59. Gorham, E. "Factors influencing supply of major ions to inland waters with special reference to the atmosphere", Bull. Geol. Soc. Amer., Vol. 72, pp. 795-840, 1961.

60. Gorr, W. L., Nagin, D. and Szcypula, J. "Comparative study in artificial neural network and stastistical models for predicting student grade point averages", Internation Journal of Forecasting, Vol. 10, pp. 17-34, 1994.

61. Gray, A.R. and MacDonell, S.G. "A comparison of techniques for developing predictive models of software metrics", Information and Software Technology, Vol. 39, pp. 425-437, 1997.

62. Groves, C.G. "Geochemical and kinetic evolution of a karst flow system, Laurel creek, West Virginia", Groundwater, Vol. 30, pp. 186-191, 1992.

63. Grubert, J.P. "Acid deposition in the eastern United States and neural network predictions for the future", Journal of Environmental Engineering and Science, Vol. 2, No. 2, pp. 99–109, 2003.

64. Gupta, A.K., Patil, R.S. and Gupta, S.K. "A statistical analysis of coastal water quality for Jawaharlal Nehru Port and surrounding harbour region in India", International Journal of Environmental Monitoring and Assessment, Vol. 95, pp. 295-30, 2004.

65. Hafizan Juahir, Sharifuddin M., Zain., Mohd. Ekhwan Toriman., Mazlin Mokhtar and Hasfalina Che Man "Application of artificial neural network models for predicting water quality index", Jurnal Kejuruteraan Awam, Vol. 16, No. 2, pp. 42-55, 2004.

66. Handa, B.K. "Modified classification procedure for rating irrigation water", soil sci., Vol.98, pp. 246-269, 1964.

67. Hardgrave, B.C., Wilson, R.L. and Walstrom, K.A. "Predicting graduate student success: A comparison of neural networks and traditional techniques", Computers and Operations Research, Vol. 21, pp. 249-263, 1994.

68. Harilal, C.C., Hashim, A., Arun, P. R., and Baji, S. "Hydro-geochemistry of two rivers of Kerala with special reference to drinking water quality", J. Ecology. Env. Conservation., Vol. 10, No. 2, pp. 187-192, 2004.

69. Harrison, R., Swift, R.S., Campbell, A.S. and Tonkin, P.J. "A study of two soil development sequences located in a montane area of Canterbury, New Zealand, I. Clay mineralogy and cation exchange properties", Geoderma, Vol. 47, pp. 261-282, 1990.

70. Hatim Elhatip, M. and AydinKo, Mu. R. "Evaluation of water quality parameters for the Mamasin dam in Aksaray City in the central Anatolian part of Turkey by means of artificial neural networks", Environ Geol, Vol. 53, pp. 1157-1164, 2008.

71. He C., Shi C., Yang C. and Agosti B.P. "A Windows-based GIS-AGNPS interface," Journal of the American Water Resources Association, Vol. 37, No. 2, pp. 395-406, 2001.

72. Hem, J.D. "Study and interpretation of the chemical characteristics of natural water", U.S. Geological Survey Water-Supply Paper 2254, 3rd Ed., Scientific Pub., Jodhpur, pp. 263, 1986.

73. Hem, J.D. "Study and interpretation of the chemical characteristics of natural water, USGS Water Supply Paper, 1473, pp. 363, 1970.

74. Hem, J.D. “Study and Interpretation of the Chemical Characteristics of Natural Waters”, Scientific Publ., Jodhpur, India,Vol. 2254, No. 3, pp. 263, 1991.

75. Hendry, M.J. and Schwartz, F.W. “The chemical evaluation of groundwater in the Milk river aquifer, Canada”, Groundwater, Vol. 23, pp. 4-9, 1990.

76. Holger, R., Maier and Graeme, C. Dandy “Neural networks for the prediction and forecasting of water sources variables: a review of modelling issues and applications”, Environmental Modelling and Software, Vol. 15, pp. 101-124, 2000.

77. Holger, R. Maier, Ashu Jain, Graeme, C. and Dandy, K.P. Sudheer “Methods used for the development of neural networks for the prediction of water resource variables in river systems: Current status and future directions”, Environmental Modelling & Software, Vol. 25, pp. 891-909, 2010.

78. Horton, R. R. “An index number system for rating water quality”, J. Wat. Pollut. Control. Fed., Vol. 37, pp. 300-306, 1965.

79. Hruschka, H. “Determining market response functions by neural network modeling: A comparison to econometric techniques”, European Good Journal of Operational Research, Vol. 66, pp. 27-35, 1993.

80. Hudson, R.O. and Golding, D.L. “Controls on groundwater chemistry in Subalpine catchments in the solution interior British Columbia”, Journal of Hydrology, Vol. 201, pp. 1-20, 1997.

81. Huiqun, M.A. and Ling, LIU. “Waterquality assessment using Artificial Neural Network”, International Conference on Computer Science and Software Engineering, pp. 13-15, 2008.

82. Ibrahim Bathusha, M. and Saseetharan, M.K. “Statistical study on physio-chemical characteristics of ground water of Coimbatore south zone”, Indian Journal of Environmental Protection, Vol.26, No.6, pp.508-515, 2006.

83. Jain, C.K. “Application of chemical mass balance in river reach: a chemical mass balance approach”, Journal of Water Resources Research, Vol. 26, No.7, pp.1549-1558, 1996.

84. Jain, P., Sharma, J. D., Sohu, D. and Sharma, P. “Chemical analysis of drinking water of villages of Sanganer Tehsil, Jaipur District”, Int. J. Environ. Sci. Tech. Vol. 2, No. 4, pp. 373-379, 2006.

85. Jensen, J.R. “Remote Sensing of the Environment: An Earth Resource Perspective”, Second Ed. Prentice Hall, 2000.

86. Jeyaraj, T., Padmavathy, S., Shirley, S. and Jebakumari, H. “Correlation among water quality parameters for ground water samples of Bharathi Nagar of Tiruchirapalli City”, Indian Journal of Environmental Protection, Vol. 22, No. 7, pp. 755-759, 2001.

87. Kalyanaraman, S.B. and Geetha, G. “Correlation analysis and prediction of characteristic parameters and water quality index of ground water”, Pollution Research, Vol. 24, No. 1, pp. 197-200, 2005.

88. Kanan, C. and Rajashekharan, “Correlation of water quality parameters of printing industry effluent in Sivakasi”, Indian Journal Environmental Health, Vol. 33, No. 3,pp. 330-335, 1991.

89. Karanth, K.R. “Groundwater Assessment Development and Management”, Tata McGraw Hill Publ. Company Ltd., pp. 610, 1987.

90. Keshvan, K.G. and Parameswari, R. “Evaluation of ground water quality in Kancheepuram”, Indian Journal of Environmetnal Protection, Vol. 25, No. 3, pp. 235-239, 2005.

91. Konhauser, K.O., Fyfe, W.S. and Kronberg, B.I. “Multi-element chemistry of some Amazonian waters and soils”, Chemical Geology, Vol. 112, pp. 155-175, 1994.

92. Lachtermacher, G. and Fuller, J. D. “Back propagation in hydrological time series forecasting in stocahstic and statistical methods in hydrology and environmental engineering”, Kluwer Academy, Norwell Mass, Vol. 3, pp. 229-242, 1994.

93. Landwehr, J.M. “A statistical view of a class of water quality indices”, Water Resource Research, Vol. 15, pp. 460-468, 1979.

94. Lawrence, A.R., Lloyd, J.W. and Marsh, J.M. “Hydrochemistry and groundwater mixing in part of the Lincolnshire linstones aquifer, England”, Groundwater, Vol. 14, pp. 36-44, 1976.

95. Lawrence, J.F. “Digital evaluation of groundwater resources in Ramanathapuram District”, Tamil Nadu, Ph.D thesis, Manonmanian Sundaranar University, Tirunelveli, pp. 291, 1995.

96. Lee, J. H. W., Wong, K.T M., Huang, Y.and Jayawardena, A.W. “A real time early warning and modelling system for red tides in Hong Kong”, Wang, Z.Y. (Ed.), Proceedings of the Eighth International Symposium on Stochastic Hydraulics, Balkema, Beijing, pp. 659-669, 2000.

97. Lee, J.H.W., Huang, Y., Dickmen, M. and Jayawardena, A.W. “Neural network modelling of coastal algal blooms”, Ecological Modelling, Vol. 159, pp. 179-201, 2003.

98. Liao, H.H., and Tim, U.S. “An interactive modeling environment for nonpoint source pollution control”, Journal of the American Water Resources Association, Vol. 33, No. 3, pp. 1-13, 1997.

99. Liong, S.Y., Lim, W.H. and Paudyal, G. “Real time river stage forecasting for flood Bangladesh: neural network approach”, Journal of Computing in Civil Engineering ASCE, Vol. 14, No. 1, pp. 1-8, 1999.

100. Mackenzie, F.T. and Garrels, R.H. “Chemical mass balance between rivers and oceans”, Amer.J.Sci., Vol. 264, pp. 507-525, 1965.

101. Mackenzie, F.T. and Garrels, R.H. “Silicates reactivity with seawater”, Science, Vol. 150, pp. 57-58, 1966.

102. Mafia, J. Diamantopoulou, Dimitris M., Papamichail and Vassilis, Z. Antonopoulos. “The use of a Neural Network technique for the prediction of water quality parameters”, Operational Research An International Journal, Vol. 5, No. 1, pp. 115-125, 2005.

103. Mahajan, S.V., Savita Khare and Shrivastava, V.S. “A correlation and regression study”, Indian Journal of Environmental Protection, Vol. 25, No. 3, pp. 254-259, 2005.

104. Makarynskyy, O. “Improving wave predictions with artificial neural networks”, Ocean Engineering, Vol. 31, pp. 709-724, 2004.

105. Manoj Khandelwal and Singh, T.N. “Prediction of mine water quality by physical parameters”, Journal of Scientific and Industrial Research, Vol. 64, pp. 564-570, 2005.

106. Mariappan, P. and Vasudevan, T. “Correlation coefficient of some physico-chemical parameters of drinking water ponds in eastern part of Sivangangai District, Tamil Nadu”, International Journal on Pollution Research, Vol. 21, No. 4, pp. 403-407, 2002.

107. Mishra, P.C., Pradhan, K.C. and Patel, R.K. “Quality of water for drinking and agriculture in and around mines in Keonjhar District, Orissa”, Indian Journal of Enviornmental Health, Vol. 45, No. 3, pp. 213-220, 2003.

108. Mohan, R., Singh, A.K., Tripathi, J.K. and Chowdhary, G.C. “Hydrochemistry and quality assessment of groundwater in Naini industrial area, Allahabad district, Uttar Pradesh”, Journal of Geological Society of India, Vol. 55, pp. 77-89, 2000.

109. Mohiuddin, K. M., Zakir, H. M., Otomo, K., Sharmin, S. and Shikazono, N. “Geochemical distribution of trace metal pollutants in water and sediments of downstream of an urban river”, Int. J. Environ. Sci. Tech., Vol. 7, No. 1, pp. 17-28, 2010.

110. Mohsen Hayati and Zahra Mohebi “Application of Artificial Neural Networks for temperature forecasting”, World Academy of Science, Engineering and Technology, Vol. 28, pp. 275-279, 2007.

111. Mohsen Nasirian “A new water quality index for environmental contamination contributed by mineral processing: A case study of Amang (Tin Tailing) processing activity”, Journal of Applied Scientific Information Vol. 7, No. 20, pp. 2977-2987, 2007.

112. Mor Suman, M.S., Bishnoi, M.S. and Bishnoi, N.R. “Assessment of ground water quality in Jind city”, Indian Jorunal of Environmetnal Protection, Vol. 23, No. 6, pp. 673-679, 2002.

113. Muhammad Ali Shamim, Ghumman A.R. and Usman Ghani. “Forecasting groundwater contamination using Artificial Neural Networks”, International Conf. on Water Resources and Arid Environment, pp. 1-8, 2004.

114. Muir, D.C.G. and Baker , B.E. “The disappearance and movement of three triazine herbicides and several of their degradation products in soil under field conditions”, Weed Research, Vol. 18, pp. 111-120, 1978.

115. Muluye, Y., Getnet and Coulibaly Paulin "Seasonal reservoir inflow forecasting with low-frequency climatic indices: a comparison of data driven methods", Hydrological Sciences Journal, Vol. 52, No. 3, pp. 508-522, 2007.

116. Muttil, N. and Chau, K.W. "Neural network and genetic programming for modelling coastal algal blooms", International Journal of Environment and Pollution, Vol. 28, No. 3/4, pp. 223-238, 2006.

117. Najah Ali, Elshafie Ahmed, Karim Othman, A. and Jaffar Othman. "Prediction of Johor River water quality parameters using Artificial Neural Networks", European Journal of Scientific Research, Vol. 28, No. 3, pp. 422-435, 2009.

118. Namade, P.N. and Shrivastava, V.S. "Pollution status of distillery wastes in Satpud region", Pollution Research, Vol. 15, No. 4, pp. 245-250, 1996.

119. Nemade, P.N. and Shrivastava, V.S. "Correlation and regression analysis among the distilery wastewater quality parameters", J. Ind. Poll. Cont., Vol. 13, No. 1, pp. 67-72, 1997a.

120. Nemade, P.N. and Shrivastava, V.S. "Groundwater pollution by industrial wastes : A statistical approach", J.Ind.Water Works Assoc, Vol. 29 No. 4, pp. 247-250, 1997b.

121. Nives, S.G. "Water quality evaluation by index in Dalmatia", Water Research, Vol. 33, pp. 3423-3440, 1999.

122. Njitchoua, R., Dever, L., Fontes, J.Ch. and Naoh, E. "Geochemistry origin and recharge mechanisms of groundwater from the Carona sandstone aquifer, Northern Cameroon," J. Hydrol., Vol. 190, pp. 123-140, 1997.

123. Okeke, C.O. and Igboanua, A.H. "Characteristics and quality assessment of surface water and groundwater recourses of Akwa Town, Southeast, Nigeria", J. Niger. Assoc. Hydrol. Geol., Vol. 14, pp. 71-77, 2003.

124. Ophori, D.U. and Toth, J. "Characterisation of groundwater flow by field mapping and numerical simulation-Ross Creek Basin, Alberta, Canada", Groundwater, Vol. 22, No. 2, pp. 193-201, 1989.

125. Palmquist, W.N. “Sampling for groundwater investigations”, Dept. of Mines and Geology. Govt. of Karnataka, Groundwater Studies, Vol. 125, pp. 14, 1973.

126. Patowary Kabita, and Bhattacharya, K.G. “Evaluation of drinking water quality of coalmining area, Assam”, Indian Jorunal of Environmetnal Protection, Vol. 25, No. 3, pp. 204-211, 2005.

127. Patuwo, W., Hu M.Y. and Hung, M.S. “Two group classification using neural networks”, Decision Sciences, Vol. 24, pp. 825-845, 1992.

128. Pejman, A. H., Nabi Bidhendi, G. R., Karbassi, A. R., Mehrdadi, N. and Esmaeili Bidhendi, M. “Evaluation of spatial and seasonal variations in surface water quality using multivariate statistical techniques”, Int. J. Environ. Sci. Tech., Vol. 6, No. 3, pp. 467-476, 2009.

129. Phiri, O., Mumba, P., Moyo, B. H. Z. and Kadewa, W. “Assessment of the impact of industrial effluents on water quality of receiving rivers in urban areas of Malawi”, Int. J. Environ. Sci. Tech., Vol. 2, No. 3, pp. 237-244, 2005.

130. Plummer, L.N. and Back, W. “The mass balance approach: application to interpreting the chemical evaluation of hydrologic systems”, American Journal of Science, Vol. 280, pp. 130-142, 1980.

131. Pradhan, S.K., Patnaik, D. and Rout, S.P. “Ground Water Quality Index for a phosphatic fertilizer plant”, Indian Journal of Environmental Protection,Vol. 21, No.4, pp. 355-358, 2001.

132. Prajapati, R. and Mathur, R. “Statistical studies on the ground water at the ruarl areas of Sheopurkalan, Madhya Pradesh”, Journal of Ecological and Environmental Monitoring, Vol. 15, No. 1, pp. 47-54, 2005.

133. Prakasa Rao, J. “Environmental evaluation of groundwater quality of a Developing Urban Area of Andhra Pradesh, India”, Ph.D. thesis submitted to Andhra University, Visakhapatnam, India, pp. 104, 1997.

134. Purandara, B.K., Varadarajan, N. and Jayasree, K. “Impact of sewage on groundwater quality?; A case study”, Pollution Research, Vol. 22, No. 2, pp. 189-197, 2003.

135. Radha Krishna, B.P. “Problems confronting the occurrence of groundwater in rocks”, Proc. Geol. Soc. India, Sem., pp. 27-44, 1971.

136. Raghunath, H.M. “Groundwater”, Willey Eastern Ind. Ltd., New Delhi, pp. 299, 1987.

137. Ramakrishnaiah, C.R., Sadashivalah, C. and Ranganna, G. “Assessment of water quality index for the groundwater in Tumkur Taluk, Karnataka State”, Indian J. Chem., Vol. 6, pp. 523-530, 2009.

138. Ramanathan, A.L., Chidambaram, S., Srinivasamoorthy, K. and Anandan, P. “Dissolved ion concentration in the surface and groundwater’s of Neyveli mining region”, UNESCO-IHP series, pp. 167-180, 2001.

139. Ramesem, V. and Barua, S.K. “Preliminary studies on the mechanisms controlling salinity in the north western region of India”, Ind. J. Geohydrology, Vol. 9, pp. 10-18, 1973.

140. Ramkumar, T., Venkatramanan, S., Anitha Mary, I., TamilSelvi, M. and Ramesh, G. “Hydro geochemical quality of groundwater in Vedaraniyam Town, Tamil Nadu, India”, Research Journal of Environmental and Earth Sciences, Vol. 2, No. 1, pp. 44-48, 2010.

141. Reckhow, K.H. “Water quality prediction and probability network models”, Canadian Journal of Fisheries and Aquatic Sciences, Vol. 56, pp. 1150-1158, 1999.

142. Rene, E. R. and Saidutta, M. B. “Prediction of water quality indices by regression analysis and Artificial Neural Networks”, International Journal of Environmental Research, Vol. 2, No. 2, pp. 183-188, 2008.

143. Rengarajan, R. and Balasubramanian, A. “Corrosion and scale formation characteristics of groundwater in and around Nangavalli, Salem District, Tamil Nadu”, J. Applied Hydrology, Vol. 3, No. 2, pp. 15-22, 1990.

144. Richards, L.A. “Diagnosis and Improvement of Saline and Alkali Soils”, Agri Handbook 60. U.S. Dept. of Agri. Washington D.C, pp. 160, 1954.

145. Ripley, B.D. “Neural networks and related methods for classification”, Journal of the Royal Statistical Society B, Vol. 56, No. 3, pp. 409-456, 1994.

146. Rita, N., Kumar, Rajal Solanki and Nirmal Kumar, J.I. "An assessment of seasonal variation and water qualit index of Sabarmati River and Kharicut canal at Ahmedabad, Gujarat", Electronic Journal of Environmenal, Agricultural and Food Chemistry, Vol. 10, No. 5, pp. 2248-2261, 2011.

147. Ryzner, J.W. "A new index for determining amount of calcium carbonate scale formed by a water", J. Amer. W.W.Assn., Vol. 36, pp. 472-486, 1944.

148. Sage and Lloyd, J.W. "Drift deposit influences on the Triassic sandstone aquifer of NW Lancashire as inferred by hydrochemistry", Q.J. Engg. Geo., Vol. 11, pp. 209-218, 1978.

149. Salchenberger, L. M., Cinar, E. M. and Lash, N. A. "Neural networks: A new tool for predicting thrift failures", Decision Sciences, Vol. 23, pp. 899-916, 1992.

150. Sanjay kumar "Correlations among water quality parameters for ground water in Barmer district", Indian Journal of Environmental Protection Vol. 13, No. 7, pp. 487-489, 1993.

151. Sastri, J.C.V. "Hydro-geochemistry of rocks of the basement complex of Karnataka State", J. Mysore Uni., Sec.B, Vol. 76, pp. 20-33, 1974.

152. Satish, B., Swarup, K.S., Srinivas, S. and Hanumantha, Rao A. "Effect of temperature on short term load forecasting using an integrated ANN", Electric Power Systems Research, Vol. 72, pp. 95-101, 2004.

153. Sawyer, C.N. and Mccarty, P.L. "Chemistry for Sanitary Engineers", 2nd Ed., McGraw Hill, New York, pp. 518, 1987.

154. Scanlon, B.R. "Physical controls on hydrochemical variability in the Inner Bluegrass Karst region of central Kentucky", Groundwater, Vol. 54, pp. 225-243, 1989.

155. Scheytt, T. "Seasonal variations in groundwater chemistry near Lake Belau, Schleswig-Holstein, Northern Germany", Hydrogeology Journal, Vol. 5, No. 2, pp. 86-95, 1997.

156. Schizas, C.N., Patticijis, C.S. and Michaclides, S.C. "Forecasting minimum temperature with short time length data using artificial neural network", Nerual Network World, Vol. 4, No. 2, pp.209-219, 1994.

157. Schoeller, H. "Hydrodynamique Duns Lekarst (Ecoulement et emm agasinment) Actes", Colleques Dou Bronila, I, AIHS et UNESCO pp. 3-20, 1965.

158. Sekhar, M.C. "Immission approach for modelling dissolved solids in a river and separation of point and nonpoint loads", Ph.D. thesis, Regional Engineering College Warangal, India, 2001.

159. Shrivastava, V.S. "A relation between COD and BOD for textile dyeing and printing effluents of GIDC area of Surat city", Journal of Indian Waterworks Association, Vol. 3, No. 4, pp. 771-773, 1991.

160. Shuhui, L., Wunsch, D., Hair, E.O. and Giesselmann, M.G. "Comparative analysis of regression and artificial network models for wind turbine power curve estimation", Jouranl of Solar Energy Engineering, Vol. 123, pp. 327-332, 2001.

161. Singanan, M. and Somasekhara Rao, K. "Chemical characteristics of Rameshwaram temple town drinking water", Indian Jorunal of Envrionemental Protection', Vol. 15, No .6, pp. 458-462, 1995.

162. Singh, A.P and Ghosh, S.K. "Water quality index for River Yamuna", Poll.Res., Vol. 18, pp. 435-439, 1999.

163. Singh, R.K. and Choudhary, M.S. "Study of physico-chemical parameters of Groundwater of Nagpur District; some correlation", 28th Annual Convention Issue of Journal of IWWA, pp.99-102, 1996.

164. Singh, S.K. "Correlation among different water quality parameters of groundwater of Jhunjhunu District, Rajasthan", 28th Annual Convention of Indian Water Works Association, Jodhpur, pp. 89-98, 1996.

165. Sinha, D.K. and Ritesh Saxena "Assessment ofdDrinking water quality at Hasanpur, J.P. Nagar: A mathematical approach", Indian Journal of Environmental Protection, Vol. 26, No. 2, pp. 163-168, 2006.

166. Sinha, D.K., Shilpi Saxena and Ritesh Saxena "Water quality index for Ram Ganga river water at Moradabad", Poll Res., Vol. 23, No. 3, pp. 527-531, 2004.

167. Sivertun Ake and Prange Lars "Non-point source critical area analysis in the Gisselo watershed using GIS", Environmental Modelling and Software, Vol. 18, pp. 887-898, 2003.

168. Smith, A.E. and Mason, A.K. "Cost estimation predictive modelling: Regression versus neural network", The Engineering Economist, Vol. 42, No. 2, pp. 137-161, 1997.

169. Solaimani, K., Modallaldoust, S. and Lotfi, S. "Investigation of land use changes on soil erosion process using Geographical Information System", Int. J. Environ. Sci. Tech., Vol. 6, No. 3, pp.415-424, 2009.

170. Sreekanth, P. D., Geethanjali, N., Sreedevi, P. D., Shakeel Ahmed, Ravi Kumar, N., and Kamala Jayanthi, P. D. "Forecasting groundwater level using artificial neural networks", Current Science, Vol. 96, No. 7, pp. 933-939, 2009.

171. Sridhar, K. "Artificial recharge potentials of upper Kadavanar basin, Dindigul Dsitrict, Tamil Nadu, using Remote Sensing and GIS", Ph.D. thesis, Madras University, pp. 265, 2001.

172. Stumn, W. and Morgan, J.J. "Aquatic Chemistry", 2nd edition, John Wiley, New York, 1981.

173. Stuyfzand, P.J. "A new hydrochemical classification of water types with examples of application", IAHS,184, pp. 89-98, 1989.

174. Subba Narasimha, P.N., Arinze, B. and Anandarajan, M. "The predictive accuracy of artificial neural networks and multiple regression in the case of skewed data: Exploration of some issues", Expert Systems with Applications, Vol. 19, pp. 117-332, 2000.

175. Subba Rao, N., Prakasa Rao, J., John Devadass, D., Srinivasa Rao, K.V. Krishna, C. and Nagameeleswara Rao, B. "Hydrogeochemistry and groundwater quality in a developing urban envirnment of a semi arid region, Guntur, Andhra Pradesh", J. Geol. Soc. India, Vol. 59, pp. 159-166, 2002.

176. Subramani, T., Elango, L. and Damodarasamy, S.R. “Groundwater quality and its suitability for drinking and agricultural use in Chithar river basin, Tamil Nadu, India”, Journal of Environmental Geology, Vol. 47, pp. 1099-1110, 2005.

177. Subramanian, S. “Hydrogeological studies in the coastal aquifer of Tiruchendur”, Tamil Nadu, Ph.D Thesis, Manonmanian Sundaranar University, Tirunelveli, pp. 308, 1994.

178. Subramanian, V., Hung, M.S. and Hu, M.Y. “An experimental evaluation of neural networks for classification”, Computers and Operations Research, Vol. 20, pp. 769-782, 1993.

179. Sundarambal Palani, Shie-Yui Liong, and Pavel Tkalich “An ANN application for water quality forecasting”, Marine Pollution Bulletin, Vol. 56 pp. 1586-1597, 2008.

180. Sunitha, V., Sudharshan, V. and Rajeshwara Reddy, B. “Hydrogeochemistry of ground water, Gooty area, Anantapur District, Andhra Pradesh, India”, Pollution Research, Vol. 24, No. 1, pp. 217-224, 2005.

181. Tam, K. Y. and Kiang, M. Y. “Managerial applications of neural networks: The case of bank failure predictions”, Management Science, Vol. 38, No. 7, pp. 926-947, 1992.

182. Tam, K.Y. “Neural network models and the prediction of bank bankruptcy”, Omega, The International Journal of Management science, Vol. 19, pp. 429-445, 1991.

183. Thengaonkar, V.P and Kulkarni, D.N. “Relationship between alkalinity and flurides”, Indian Journal of Environmental Health. Vol. 13, No. 2, pp. 144-153, 1971.

184. Tiwari, T.N. and Manzoor Ali. “Water quality index for Indian rivres”, Ecology and pollution of Indian Rivers, Ed. R.K.Trivedi, Ashish publishing House, New Delhi, pp. 271-286, 1988.

185. Tiwari, T.N. and Manzoor Ali. “Groundwater of Nuzrid Town: Regression nad chemical analysis of water quality parameters”, Indian Journal of Environmental Protection, Vol. 9, No.1, pp. 13-38, 1989.

186. Tiwari, T.N. and Mishra, M. “A preliminary assignment of water quality index of major Indian rivers”, Indian Journal of Environmental Protection, Vol. 5, Vol. 4, pp. 276-279, 1985.

187. Tiwari, T.N., Das, S.C. and Bose, P.K. “Correlation among water quality parameters of groundwater of Meerut District”, Acta Sciencia Indica. Vol. 12, No.3, pp. 111-113, 1986.

188. Tiwari, T.N., Das, S.C. and Bose, P.K. “A relationship between COD and BOD for the Ganga River at Kanpur”, Indian Journal of Environmental Protection, Vol. 6, No.4, pp. 183-184, 1986 a.

189. Todd, D.K. “Groundwater Hydrology”, John Wiley and Sons, New York, pp. 535, 1980.

190. Usha, A. and Kumar “Comparison of neural networks and regression analysis: A new insight”, Expert Systems with Applications, Vol. 29, pp. 424-430, 2005.

191. Vahidnia Mohammad, H., Alesheikh Ali, A. and Abbas Alimohammadi Farhad Hosseinali “A GIS-based neuro-fuzzy procedure for integrating knowledge and data in landslide susceptibility mapping”, Computers and Geosciences, Vol. 36, No. 9, pp. 1101-1114, 2010.

192. Venkatachalam, M.R. and Jebanesan, A. “Correlation among water quality parameters for groundwater in Chidambaram Town”, Indian Journal of Environmental Protection, Vol. 18, No. 10, pp. 734-738, 1998.

193. Wagh, S.P. and Shrivastava, V.S. “Relation between COD and BOD in sewage and ground water samples aroun Nasik City’, Indian Journal of Environmental Protection, Vol. 27, No. 2, pp. 165-167, 2007.

194. Warner, B. and Misra, M. “Understanding neural networks as statistical tools”, The American Statistician, Vol. 50, No. 4, pp. 284-293, 1996.

195. Wen, C. G and Lee, C.S. “A neural network approach to multi objective optimization for water quality mangement in a river basin”, Wat.Resourcres Res., Vol. 34, No. 3, pp. 427-436, 1998.

196. WHO “Guidelines for Drinking Water Quality”, World Health Organization, Geneva, 1984.

197. Williams, M., Kattelmann, R. and Melack, J. “Groundwater contributions to the hydrochemistry of an Alpine basin’ Hydrology in Mountainous Regions I – Hydrological Measurements; the Water Cycle, Proceedings of two Lausanne Symposia”, August 1990, IAHS Publication No.193, pp. 741-748, 1990.

198. World bank report, 1995, http://www-wds. worldbank. org/external/ default/WDSContentServer/IW3P/IB/1999/04/28/000009265_3961219 103803/Rendered/PDF/multi0page.pdf

199. Xiaoqing Zeng and Todd C. Rasmussen “Multivariate statistical characterization of water quality in Lake Lanier, Georgia, USA”, Journal of Environmental Quality, Vol. 34, pp. 1980-1991, 2005.

200. Yunchao Jiang and Zhongren Nan “Integration of Artificial Neural Network with GIS in uncertain model of river water quality”, Geoscience and Remote Sensing Symposium. IEEE International Conference, pp. 3386-3389, 2006.

201. Yuretich R. F. and Batchelder G. L. “Hydro-chemical cycling and chemical denudation in the Fort River Watershed, Central Massachussetts: An Approach of Mass Balance Studies”, Water Resources Research, Vol. 24, No. 1, pp. 105-114, 1988.

202. Zaheer and Bai C.G. “Application of Artificial Neural Network for water quality management”, Lowland Technology International, Vol. 5, No. 2, pp. 10-15, 2003.

203. Zhang Q. and Stanley S. J. “Forecasting raw-water quality parameters for the North Saskatchewan River by Neural Network Modelling”, Water Research, Vol. 31, No. 9, pp. 2340-2350, 1997.

LIST OF PUBLICATIONS

1. Gajendran, C. and Thamarai, P. “Study on statistical relationship between ground water quality parameters in Nambiyar River basin, Tamil Nadu, India”, International Journal on Pollution Research, Vol. 27, No. 4, pp. 679-683, 2008.

2. Gajendran, C. and Thamarai, P. “Relation between surface water qualities assessment in Nambiyar River basin, Tamil Nadu, India: A statistical Approach”, International Journal of Future on Future Engineering and Technology, Vol. 4, No.2, pp. 27-33, 2008.

3. Gajendran, C. “Assessment Of Contamination in River basin using GIS” in UGC Sponsored State Level Seminar in “River, Riverside Ecology and Economy” Organized By The P.G Department Of Zoology And Economics, St. John’s College, Playamkottai, pp. 123-131, 2007.

4. Gajendran, C., Thamarai, P. and Baskaran “Water quality evaluation for Nambiyar river basin, Tamil Nadu, India by using geo-statistical analysis”, Asian Journal of Microbiology, Biotechnology and Environmental Science, Vol. 12, No. 3. pp. 555-560, 2010.

5. Gajendran, C., Thamarai, P. and Mahendran, C. “Application of Artificial Neural Network in water resources engineering: a review” article, International Journal of Future on Future Engineering and Technology, Vol. 5, No. 4, pp.1-5, 2010.

CURRICULUM VITAE

Mr.Gajendran C has received his Bachelor degree in Civil Engineering from Madurai Kamaraj University, Madurai in the year 1999 and he obtained his Master of Engineering with the specialization of Environmental Engineering from Anna University, Chennai in the year 2004. He is also holding two Diploma degrees viz, Diploma in Rail Transport and Management from Institute of Rail Transport, New Delhi and Diploma in Industrial Safety from Annamalai University, Chithamparam.

He started his carrier in the year 2004 as a Lecturer in Sardar Raja College of Engineering, Alangulam, Thenkasi. In the year 2007 he joined as a Lecture in School of Civil Engineering, Karunya University, Coimbatore. Currently he is working as an Assistant Professor in School of Civil Engineering, Karunya University, Coimbatore. He has more than 10 years of teaching experience. His area of research includes water basin modeling, GIS, Application of ANN in Water Technology, Isotope technologies and model surveying. Presently he is pursuing a Project in the isotope application are as a principle investigator which is being funded (Rs.17.17 lakhs) by Department of Science and Technology, Government of India. He has more than 20 research publications in renowned International Journals and conferences.